NUCLEAR ENGINEERING

VOL. I NO. 9 DECEMBER, 1956

PRINCIPAL CONTENTS

page

ATOMIC ENERGY IN EASTERN EUROPE: POLAND *by* **J. F. Calor**
L'Energie Atomique en Europe Orientale: 1ère partie—Pologne
Atomkraft in Ost-Europa: Teil 1—Polen
Energía Nuclear en Europa Oriental: Parte 1—Polonia 363

THE FEASIBILITY OF A COAL-DRIVEN POWER STATION *by* **O. R. Frisch**
La Praticabilité des Génératrices actionnées au charbon
Moglichkeiten für mit Kohle als Brennstoff arbeitende Kraftwerke
Posibilidad de las Centrales eléctricas mandadas por carbón 368

THE NEW SOURCE OF ENERGY *by* **H. G. Wells**
La Nouvelle Source d'Energie
Die neue Energiequelle
La Nueva Fuente de Energía 370

INDUSTRIAL ENTERPRISE
Les Etudes et la Fabrication chez Babcock & Wilcox, Ltd., Renfrew
Forschung und Produktion bei Babcock & Wilcox Ltd., Renfrew
Investigación y fabricatión en la firma Babcock & Wilcox Ltd., Renfrew, Escocis . . 371

PROBLEMS OF LIQUID-METAL-FUELLED REACTORS *by* **B. R. T. Frost**
Problèmes soulevés par les Réacteurs à combustible metal liquide
Probleme der Flüssig-Metall-Reaktoren
Los Problemas de Reactores Alimentados con Metal Liquido 373

FABRICATION AND WELDING TECHNIQUES FOR ATOMIC ENERGY PLANT
Les Techniques de Fabrication et de Soudure pour les récipients et la tuyauterie
Zusammenbau von Behältern und Rohrsystemen und die dabei zur Anwendung kommende Schweisstechnik
Técnicas de fabricacion y soldadura de recipientes y tuberias 378

B.N.E.C. SYMPOSIUM ON CALDER HALL
La Conference de l'Energie Nucleaire Britannique sur Calder Hall
Britische Konferenz über Atomkraft und Calder Hall
Conferencia Britanica de Energía Nuclear con relación a Calder Hall 383

THE WORLD'S REACTORS: NO. 6—CALDER HALL
Les Réacteurs dans le Monde: Numero 6—Calder Hall
Reaktoren in der Welt: Zahl 6—Calder Hall
Los Reactores del Mundo: Numero 6—Calder Hall . . . . . facing 388

DIDO 391

REGULAR FEATURES

EDITORIALS 359
COMMENTS ON THE NEWS . . 361
WORLD NEWS 393
ORBITS IN INDUSTRY . . . 395
TRADE NOTES 396
PERSONAL 397
PROCESSES AND EQUIPMENT . 398
PATENTS REVIEWED . . . 400

Proprietors:
TEMPLE PRESS LIMITED

Chairman and Managing Director:
ROLAND E. DANGERFIELD

Editorial Director:
A. P. CHALKLEY, B.Sc. (Eng.)

Editor:
E. N. SHAW, B.Sc.

Head Office:
BOWLING GREEN LANE, LONDON, E.C.1
Telephone: Terminus 3636 (Private Exchange).
Inland Telegrams: "Pressimus London Telex."
Telex: 2-3039.
Cables: "Telex 2-3039=Pressimus London."

ANNUAL SUBSCRIPTION RATE 42/-
(Canada and U.S.A. $7.00) postage included.

PUBLISHED IN GREAT BRITAIN BY TEMPLE PRESS LIMITED, LONDON, ENGLAND

Reactor Instrumentation

Ekco Electronics have made vital contributions to the instrumentation of the existing reactors at Harwell and Calder Hall, and are responsible for the nucleonic instrumentation of the reactors under construction in Australia, and at Harwell and Dounreay. This marks yet another important step in the long line of Ekco achievements in nucleonic measurement—a field in which we were pioneers and in which we continue to lead.

EKCO

nucleonics electronics

REACTOR INSTRUMENTATION
HEALTH MEASUREMENT
SPECTROMETRY
INDUSTRIAL MEASUREMENT
MEDICAL AND GENERAL COUNTING
ANCILLARY EQUIPMENT

EKCO ELECTRONICS LIMITED
EKCO WORKS · SOUTHEND-ON-SEA · **ESSEX**

NUCLEAR ENGINEERING VOL. 1 NO. 9 DECEMBER, 1956

EDITORIALS

Manufacturing for Nuclear Applications

". . . but few manufacturers supply equipment to the standard required for atomic energy applications on a first attempt".

THE remark printed above was made during a casual conversation with a member of the Atomic Energy Authority, and because of its implications we have attempted to find out how valid such a generalization is. It should, perhaps, be emphasized that this in no way represented an attack on industry as a whole by the person concerned, and the sweeping nature of the remark was not intended to convey the impression that the construction of, say, Calder Hall had been one long, uphill fight to obtain the necessary quality of manufacture. The criticism was largely levelled at the component manufacturer and the supplier of either standardized equipment or standard equipment modified for a particular application.

Whilst not accurate in 100% of the cases, it would appear that a very strong tendency exists for the statement to be true, at least in substance. Little purpose would be served by being specific on the instances of faulty manufacture, but it would seem that whilst suppliers are still unfamiliar with the special problems of nuclear engineering, the reliability of many components could be improved. There are many industrial processes where complete reliability of operation is of vital importance, and these industries have been served for many years by the same manufacturers without serious interruption and without much heartbreak. Rarely, however, in industrial processes is one required to supply plant which not only must give absolute trouble-free running but which is inaccessible for a large part of its working life and which handles materials of such value as, say, heavy water. There are also few processes in which failure of operation can cause as much disorganization as in the operation of a nuclear reactor. Particularly in a new type of reactor or a research reactor where a number of unknowns are bound to be present, set-backs caused by small plant failures can be of great seriousness. Failure of even a minor component of an ancillary plant which serves a further ancillary plant and which, in turn, is concerned with the operation of the reactor can cause a serious dislocation in operation.

Instrumentation in the reactor system will guard against such failures causing a major catastrophe, but even minor set-backs are, to say the least, expensive and time-consuming and it is not inconceivable that a series of coincident minor faults, particularly on a research reactor, could cause an unpleasant situation.

It is absolutely essential, therefore, that all plant, without exception, associated with the reactor be built to the highest standard with the maximum reliability possible. This usually involves a greater initial expenditure, but certainly at the present time this expenditure will always be justified.

Leaving aside any fallacy in design which can always occur in the development of new plant, much can be done to ensure that familiar components are designed with maximum performance in mind and manufactured to the standard of workmanship that is necessary. Clearly, a component which is normally available in the market will have been built to a reasonably rigorous specification and will only have been selected if its general performance figures are satisfactory; but few manufacturers would claim that 100% of their products give completely trouble-free service on installation and it is probable that the extra cost of production and inspection to ensure this could not be justified on economic grounds. It is necessary, therefore, for equipment to be installed in reactor applications to be selected equipment which has received unusual and, at a first glance, what might seem excessive inspection and an unusually long trials period. For example, sample testing on a production run will not be sufficient and all components will require to be given a running test.

There can be little question that numerous cases exist where these precautions have not been taken and, although no serious hold-ups have resulted, there have been numerous minor ones in the construction of reactors, and some reactor plant has needed rebuilding after initial installation. Two morals can be drawn from this. First, industry must appreciate the particular problems involved in nuclear engineering and plan its supplies (and quotations) on the assumption that rigorous manufacturing inspection and some redesign must be included. Second, the manufacturer must be taken fully into the confidence of the plant designer, so that he may be able to appreciate at an early stage in the contract the particular problems involved and so that he can obtain the advice of the designer, who, in turn, can be made to appreciate the problems of the manufacturer and effect replanning where necessary. Real co-operation between the customer and supplier on these points can result not only in a better product but also, in the long run, a cheaper product.

International Atomic Energy Agency

DISCUSSIONS which began on September 20 amongst 81 nations on the establishment of an international atomic energy agency were successfully concluded on October 24. The Agency had been originally proposed in 1953 by President Eisenhower and a draft statute had been drawn up by a twelve-nation committee in June of this year. The details of the charter have evoked considerable discussion, for the most part confined to details of working. The setting up of safeguards, however, has caused some dissension, but the terms of the final draft statute were unanimously approved.

The object of the Agency is set down as being to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. It shall ensure, as far as possible, that the assistance provided under its auspices is not diverted into military channels. The Agency is authorized to encourage and assist research on, and development and practical application of, atomic energy for peaceful uses and to act as an intermediary between suppliers and users of member nations. The exchange of scientific and technical information is considered of great importance, and provision is made for the encouragement and exchange of scientific personnel between member countries. The Agency is charged with the establishment and administration of safeguards designed to ensure that special fissionable and other materials, services, equipment, facilities and information made available by the Agency are not used in such a way as to further any military purpose, and to apply safeguards at the request of the parties to bilateral or multilateral arrangements or at the request of a state to any of that state's activities in the field of atomic energy. In consultation with the appropriate organs of the United Nations, standards for the protection of health and the minimization of dangers are to be set up. The Agency will acquire or establish any facilities, plant or equipment useful for carrying out its authorized functions whenever the facilities in the area concerned are inadequate or available only on terms it deems unsatisfactory.

In carrying out its functions, particular attention is to be paid to the under-developed areas of the world, and the aim is to secure the greatest possible general benefit, irrespective of nationality.

In addition to those U.N. members who have signed the statute within 90 days after its opening for signature, members can include states who deposit an instrument of acceptance of the statute, provided approval is given by the General Council upon the recommendation of the Board of Governors.

At the General Council meeting, which will be held annually, member countries will be represented by one delegate, all with equal voting capacity.

The Agency will have its day-to-day business run by a Board of Governors consisting of 23 representatives. The outgoing board, or in the case of the first board the preparatory commission, will designate five members from those countries most advanced in atomic energy technology and a further five members from each of the areas not represented by the aforesaid five. The areas are defined as North America, Latin America, Western Europe, Eastern Europe, Africa and the Middle East, South Asia, South-east Asia and Pacific, and the Far East. The important producers of source materials—Belgium, Czechoslovakia, Poland and Portugal—will supply two members (these cannot be redesignated the following year) and a further member as supplier of technical assistance also for one year only. The outgoing board therefore designates, in effect, 13 members for the following year as it can be assumed, at least initially, that the five members drawn from the advanced countries will be from three areas and will consist of the U.K. and France, Canada and the U.S.A. and the U.S.S.R.

In addition, ten members will be elected by the General Council to serve a two-year period. For the first period five of these members will be for one year only to allow five to be elected every year. Provision is also made that representatives elected in the two-year office cannot be elected for the following two years. It is intended that the ten members elected by the General Council should be drawn from as wide an area as possible to allow world-wide representation.

Each member of the Board of Governors is to have one vote, and financial matters will require a two-thirds majority, a quorum being formed by two-thirds of the full membership of the board. The responsibility for the elections of the chairman and other officers is left to the Board of Governors itself.

The permanent staff of the Agency will be headed by a director-general, who will be appointed by the Board of Governors with the approval of the General Council for a term of four years. The Agency will be guided by the principle that its permanent staff should be kept to a minimum. Of paramount consideration is the recruitment of staff of the highest technical competence and integrity, drawn on as wide a geographical basis as possible.

Each member, the statute declares, should make available such information as would, in the judgment of the member, be helpful to the Agency and all scientific information developed as a result of assistance extended by the Agency. Members may make available to the Agency such quantities of special fissionable material as they deem advisable and on such terms as shall be agreed with the Agency. These materials may, at the discretion of the member, be stored either by the member or in the Agency's depots (with the Agency's consent). Such materials made available will, in general, be for a period of one calendar year. In storing material, the Agency is required to ensure that geographical distribution is such as not to allow concentration of such materials in any one country or region of the world.

Any member or group of members of the Agency desiring to set up any project for research or development or practical application of atomic energy for peaceful purposes may request assistance from the Agency in securing special materials, services, equipment and the facilities necessary. In extending assistance, the Agency will not be required to provide any guarantees or assume any financial responsibility for the project. For the purpose of considering a request, the Agency may send into the territory of the member representatives qualified to examine the project. Such examiners would be drawn either from the Agency staff or suitably qualified nationals of any member nation. Before approving such a project, the board will consider the project's usefulness and adequacy of plans, funds and technical personnel, the adequacy of the proposed health and safety standards for handling and storing materials, the availability of materials and the resources, with particular reference to the special needs of the under-developed areas of the world.

The Agency, in connection with its sponsored projects, reserves the right to examine the design of specific equipment and facilities, including nuclear reactors, and to approve such projects from the viewpoint that it will not further any military purpose. It reserves rights to send into the territory of the state or states inspectors designated by the Agency after consultation with the state or states concerned, who shall have access at all times and all places to data and to any person who, by reason of his occupation, deals with materials, equipment or facilities which are required by the statute to be safeguarded.

Comments on the News

B.N.E.C. SYMPOSIUM

The assertion of one of the first participants in the discussions that the symposium on Calder Hall, held at the Central Hall, Westminster, on Thursday and Friday, November 22 and 23, was probably the most important conference that has ever, or will ever, be held aroused general amusement. It is no reflection on the organizers that the symposium was far less important than it could have been. There has been general disappointment at the lack of detail in many of the papers and the reluctance to be specific on some of the more important aspects. The most serious omission in the conference, however, was the failure to appreciate the fact that a considerable section of the visitors to the conference was interested in the possibility of importing from the U.K. base-load stations of the Calder Hall type. It became clear during the symposium that the representatives from the four consortia were more interested in asseverating their good relations with the A.E.A. and with the C.E.A. and in ensuring a large and comfortable home market than in giving the world the impression that they were in serious business for the export of complete power stations capable of generating power at a cost comparable with that obtained from conventional stations. There is no question that fuel will be made available and that agreements for reprocessing can be worked out to the satisfaction of both supplier and customer. This should have been stated clearly and emphatically, so that no possible question could remain in the minds of visitors from overseas. Instead, we heard much of the future possibilities of such irrelevances as gas turbines and of the market for 30-MW and 60-MW reactors. It is imperative that our big four should state unequivocally that there is not only a market for power stations with individual reactor systems generating from 100-150-MW electricity, but that designs for these are complete and available.

MARINE PROPULSION PROBLEMS

The meeting between shipowners and shipbuilders and the Atomic Energy Authority at Harwell on October 21 has met with only partial success. The major difficulty would appear to be a fundamental lack of appreciation on both sides of the problems besetting the other. On the one hand, there is a feeling amongst certain sections of the A.E.A. that the enthusiasm of the shipping world to foster a programme of atomic energy propulsion could be greater; whereas, on the other hand, the shipbuilders and owners left with a feeling that at present the examination of reactor systems has not sufficiently taken into account the problems of constructing an economic system of power generation which is capable of installation in a ship with its big problems associated with rolling and pitching, confined design, not to mention the international questions that must be settled on the operation of such a ship in the world's main ports. It is by no means premature even at this stage that the industrialist should be acquainted with the state of present-day development and should be put in a position where he can begin to formulate his own ideas on the type of construction that is most likely to be satisfactory. In spite of the experience of the *Nautilus*, it must be acknowledged that an economic mercantile propulsion unit could be a long way off, but that is not to say that the problems should not be considered seriously at this stage. Clearly, it is the responsibility of the U.K.A.E.A. to acquaint the shipbuilding industry with the state of the technology and to encourage it to take an active consideration of future designs. At the same time, the industry must accept the responsibility of acquainting the Authority with the big problems of ship propulsion, so that at an early stage design studies can be undertaken which can have an immediate application when complete. It would no doubt ease the situation if conferences of the type that were held at Harwell could be organised regularly and if the number of representatives from industry could be reduced to a figure where more personal discussions could take place. *Nuclear Engineering* will, in the course of the next few months, present the views of both sides in an attempt to clarify the main points of difference that at present exist. It is essential, however, that a fully co-operative attitude should be adopted by both parties and that industry should be prepared to learn from the A.E.A. the particular problems associated with nuclear engineering, and that the A.E.A., in its turn, should recognize the superior knowledge of the industry with regard to the installation of power units in seagoing craft.

NEW CONSORTIUM

There is reason to suppose that a new group of companies is to enter the atomic energy field. It has been reported that a consortium has been formed consisting of International Combustion Ltd., Richardsons, Westgarth and Co. Ltd., Crompton Parkinson Ltd. and Trolloppe and Colls Ltd. At the time of going to press, however, no official statement had been issued by these companies. The inclusion of Richardsons, Westgarth in the group might suggest that at least some of the interest will be in the mercantile field, but it is generally believed that the Calder Hall type is to form the initial basis for the group's work.

TECHNICAL EDUCATION

In the first of the Reith lectures, Sir Edward Appleton, F.R.S., principal and vice-chancellor of the University of Edinburgh, stated that "it is little use strengthening and expanding our university departments for teaching and research in the applied sciences . . . if such work is going to be regarded as a second-rate activity". Apart from the overall shortage of scientists and technicians, there is an increasing view that far too little effort is devoted in this country to the training of men in the applied sciences who have a thorough knowledge of the fundamentals and a specialized knowledge of the practical aspects. The U.K. has for many years been regarded as one of the main centres of pure research and, in the field of atomic energy, history shows that a very considerable contribution has come from U.K. universities. The problem, however, of our educational system is shown in many industries where the development of new ideas in the laboratories is unequalled anywhere in the world, but where the developments from the laboratory to the final production article cannot compete with, say, the U.S.A. The development and production engineer is required in much greater quantity than the academic engineer and scientist; but at present all our basic training is concerned with the academic side and there is still a tendency for the philosophy to be implanted in the undergraduate's mind that pure research is the most honourable line to take up on completion of his course. The same situation is also reflected in executive positions, where too often, particularly in the smaller companies, they are filled by people without technical training, which results in technical decisions being made by people with insufficient background. We require, therefore, to produce two types of technical men who do not exist today, or only by chance or through the foresight of the very big organizations and the technical colleges. These are the practical engineers with a sound, fundamental training and the executives who have been taught not only administration but also have had an initial training in technical matters.

RESEARCH STATION FOR DORSET

At its meeting on November 9, the Dorset County Council agreed to the Planning Committee's recommendation by a vote of 71 to 16 to grant permission for the use of a site at Winfrith for the building of an atomic energy research station. Moving the recommendation, Lt.-Col. G. W. Mansell said that nowhere in the experts' report considered by the Council was there any possible ground for fear as to the effects of the extraction of a large amount of water. Water from bore holes at West Stafford would be limited to a maximum of 3 million gallons per day, subject to review at the end of five years. Water from the River Frome or from river gravels would be also limited to a maximum of 3 million gallons per day, of which some 40% would be returned to the River Frome.

The site had been selected by the A.E.A. from amongst a total of 70 sites within reasonable travelling distance of Harwell. One of the opposers of the proposition suggested that, with modern air transport, the requirement of being within 100 miles of Harwell was not valid. Whilst this view might be supported in the days to come when regular helicopter services are a commonplace, few regular travellers by air would agree at the present time. The time taken to reach convenient airports, the risk of fog diversion and flight cancellation are very strong deterrents to using this means of transport, except to really remote sites such as Dounreay. Liaison with the parent establishment as a result must suffer. Quite apart from the waste of time, the cost of transport over long distances must also be taken very seriously into account.

CALDER HALL SHUT-DOWN

The nuclear power station at Calder Hall has been restarted after a series of routine checks. Over six months have elapsed since the original start-up and three months' operation at power has been completed. Shut-down in November has always been part of the programme to allow comprehensive checks to be made of the condition of the fuel elements and of the pressure vessel. Sample fuel elements will be examined by television equipment for signs of irregular cooling and measurements taken of the creep.

Preliminary information on the state of the fuel elements after six months is most encouraging and the indications are that corrosion, bowing and creep have been better than anticipated. Considerable publicity has been given to the leakage loss from the first reactor amounting to approximately 1 ton CO_2 per day. It should be borne in mind that, at the pressures involved, it represents a total leakage area of approximately 2 sq. mm., which is probably distributed amongst eight or ten different joints. A programme of work is now in hand involving the enclosing of suspect joints in plastic bags to determine in detail the position of these leaks, but it is probable that the bulk of the loss comes from the ancillary circuits where there are a number of valves with conventional packed glands. Of greater significance is the considerable improvement of reactor No. 2 circuit under vacuum test, showing that the experience gained on No. 1 has enabled the commissioning engineers to eliminate almost completely this source of trouble.

AIRCRAFT PROPULSION

At a recent meeting of the Royal Aeronautical Society, Mr. E. P. Hawthorne, managing director of Hawker-Siddeley Nuclear Power Group, gave his views on the possibility of using atomic energy for the propulsion of aircraft. He suggested that one solution to the problems of shielding might be to build remotely-controlled tugs which would remain in the air semi-permanently and would provide towing power for long distances at high speeds (say Mach $2\frac{1}{2}$). The towed craft would, of course, have to be provided with engines to get them off the ground and also to land, so that savings in fuel would only be in level flight. The Hawker-Siddeley Nuclear Power Group are thinking in terms of the liquid-metal-fuelled reactor as the type most likely to be suitable for this form of work, but it is recognized that vast resources might be required to build an aircraft propelled by nuclear power. The value of launching such an enterprise is open to question. The necessity of undertaking such development for military purposes must be argued in terms of an overall defence policy, but due consideration should be given to the position of the U.K. in relation to the probable aggressive countries, and we should not be misled by policies evolved for the U.S., where the distances to be covered are of a much greater magnitude. It could be argued that, with the present national alliances, the location of U.S. bases in the U.K. presents a common defence argument for the two countries together, but the resources of the U.S. are considerably greater than those of the U.K. and we must be wary of entering a development race of the kind envisaged purely for its own sake.

It will be many years (and perhaps never) before international agreements can be worked out to permit the operation of nuclear-powered civil planes, partly because of the radiation safety aspect and partly because of the dangers of flying craft with only ancillary power built in; so the normal auxiliary argument in favour of military development, because of the potential civilian application, is not valid in this instance. Until such time as compact, land-based power plants have been developed to the point at which they are a real practical proposition, the value of embarking on a nuclear aircraft programme should be very carefully considered.

B.S.I. ACTIVITIES

The statement recently circulated by the export panel of the British Standards Institution to industrial and trade associations for further widespread distribution summarizes its policy with regard to international work on standards. The export panel thinks it essential that the country should participate actively and with the best possible representation on the committees of I.S.O. and I.E.C., so that internationally agreed recommendations can take proper account of views of British industry and British exporters. The statement makes the realistic comment that, where well-conceived and widely accepted British standards already exist, our influence on an international recommendation is so much the greater and for this reason our standards should be prepared initially taking full account of practice overseas. In the past Britain has tended to be slow, not only in standardizing throughout the country but in acknowledging the different view points held abroad. Our archaic monetary and weight systems are abundant evidence. The early recognition of the benefits of standardization, not only in terminology but in manufacturing techniques, could be of considerable value. The last war encouraged clearer thinking on this point and was largely responsible for the high degree of standardization in, for example, the thermionic valve industry where, without a drastic change in policy in the war, inevitable chaos must have resulted.

UNCLEAR TIMES

The satire by Professor Frisch was, in its original form, privately circulated in the years prior to 1950, at which time the differences in approach between the physicist and the engineer were probably more marked. We reprint it now (page 368) in a slightly modified form, partly because we think many readers will have never seen it and will enjoy a little lighter relief during the Christmas period and partly because the highly theorized conceptions of feasible systems are not yet completely dead. It is probable, furthermore, that there will be many meetings in the future during which the refrains from our short verses, suitably set to music, could be chanted with telling pertinence.

Atomic Energy in Eastern Europe

by
J. F. CALOR

PART 1—POLAND

Russian scientific and technical assistance. Work of the Nuclear Research Institute and facilities being provided at Warsaw and Cracow. Power reactor research is being concentrated on ship propulsion. Comprehensive plans for organization of training.

PRIOR to 1955, nuclear research and the application of atomic energy were not regarded as matters of urgent national importance in Poland and Czechoslovakia. The feeling prevailed that neither had enough technical resources to pursue such ambitious aims and that other tasks, especially those of industrial construction, were much more urgent. The scientists had little contact with either Soviet or Western colleagues and although some research, in theoretical physics in particular, had been carried on since 1945, it had little impact on practical developments.

All this changed in the course of 1955. The Soviet Government announced on January 17, 1955, that five countries from which the U.S.S.R. had for some time past been receiving atomic materials, China, Poland, Czechoslovakia, Rumania and East Germany, were to be granted scientific and technical assistance which would enable them for the first time seriously to enter the nuclear field. In accordance with agreements reached in the spring of 1955, each of these countries is to receive from the U.S.S.R. a research reactor of 2,000 kW (China will get a higher powered reactor) and a cyclotron, quantities of radio-isotopes, and facilities for training scientists and technicians at U.S.S.R. atomic establishments.

The Geneva Conference served as a further impetus for moving atomic energy matters into the centre of public interest. By the autumn of 1955 all the Communist governments of Eastern Europe were busy drawing up extensive schemes for large-scale all-round atomic energy expansion.

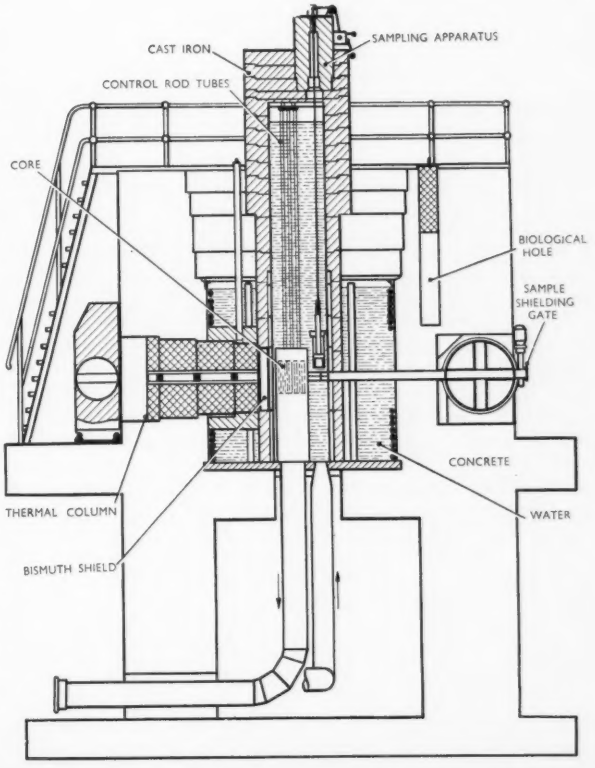
In the rigidly centralized Communist economies, economic expansion proceeds at a very uneven pace. Whilst industries such as steel production, armaments or aviation may forge ahead very rapidly, others, such as agriculture, transport or housing, remain undeveloped and backward. Favoured sectors are able to progress rapidly, because, being the Government's priority projects, they receive the most capable scientists and technicians, ample funds, allocations of scarce materials, facilities for building, etc. All over Eastern Europe since 1955, and much earlier in the Soviet Union, atomic energy development has become one of the top government priorities; large and constantly increasing resources are being directed into the nuclear expansion programme and, if the past is any guide, within the next five to ten years these countries will have become important centres of world nuclear science and technology.

Polish traditions in nuclear research go back to Marie Curie-Sklodowska and her efforts to foster the study of physics and radioactivity in Poland. The Radiological Laboratory of the Warsaw Scientific Society, founded in 1913 by Mme. Curie-Sklodowska, was the chief centre for the study of nuclear physics in Poland between the wars, carrying out research on natural and artificial radioactivity, radiochemistry, cosmic rays and the structure of the atom. The pre-war Warsaw Institute for Experimental Physics, directed by Prof. Pienkowski, was one of the best equipped in Europe, but during the war research work stopped and scientists dispersed.

Nuclear research was taken up again in 1945-6 by the Experimental Physics Research Institute under Prof. Pienkowski (who died in 1952). Its work was later supported by the formation of the Theoretical Physics Research Centre under Prof. Infeld. An Institute of Physics of the Polish Academy of Sciences was established in 1953.

Work on theoretical nuclear physics was taken up by a number of young and able physicists who concentrated their efforts on the quantum theory. In 1953, two young scientists, Pniewski and Danysz, discovered a new phenomenon in the atomic nucleus, the bound hyperon. A number of interesting results was also obtained in Cracow by Professor Niewodniczanski and Dr. Janik in their investigations of the structure of molecules with slow neutrons.

In the field of reactor technology, preparatory work on the

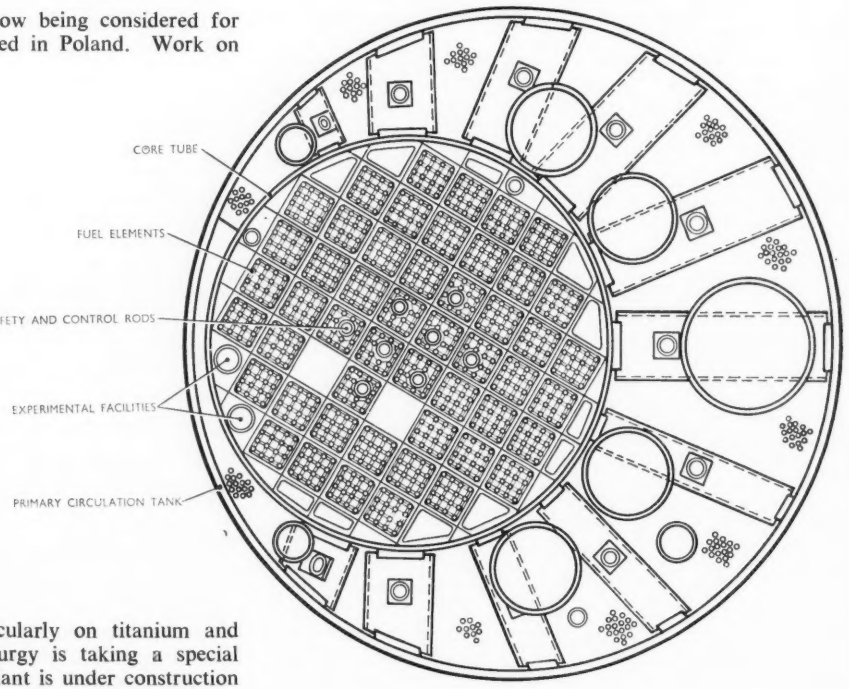


Vertical section of the 2,000-kW research reactor which is being supplied by Russia to a number of Communist countries. It is moderated by ordinary water, a 10% enriched uranium fuel being used. It has a number of horizontal and vertical facilities as well as a thermal column.

building of a Polish reactor, probably of the graphite-moderated, natural-uranium type, was initiated by B. Buras and his collaborators. Although their work will be utilized for the further development of reactor techniques, the first reactor to be built in Poland will be one imported from the Soviet Union, its cost being three times lower than the Buras reactor.

Several problems connected with the construction and operation of reactors have been pursued for the past few years. Work is proceeding on methods of extracting pure uranium and of refining and remelting spent fuel. Experience gained in the use of ion exchangers in chromatographic columns is being adapted for the separation of fission projects. Methods for detecting trace quantities of boron or cadmium in materials intended for reactors were evolved by Polish chemical scientists in 1954 and 1955. Several ways of producing pure graphite of moderator quality from Polish raw materials have been devised, and work is now afoot to produce it on an industrial scale.

Ores of some of the elements now being considered for construction were recently discovered in Poland. Work on refining them is proceeding, particularly on titanium and niobium. The Institute of Metallurgy is taking a special interest in this; a metallic sodium plant is under construction in Silesia. Poland is also the biggest Communist producer of cadmium; the annual production has been estimated at 300 tons.[2]



Plan of the reactor core of the Russian 2,000-kW research reactor. The core comprises 52 units, each of which contains 16 fuel elements, except those containing the control rods, which have 15. The control rods are of boron carbide.

In co-operation with other laboratories, the State Telecommunications Institute has constructed a range of instruments for use in conjunction with nuclear reactors, and various Geiger counters and other radiation-measuring instruments have also been built in Cracow by Prof. Miesowicz.

However, according to Prof. Infeld: "In Poland we are very backward in this field of atomic science."[3] The construction of laboratories and research equipment, such as accelerators, has in the past proceeded very slowly. The Warsaw Van de Graaff machine has been under construction for several years and has only just been completed. The chief reason for these delays has been the fact that the physicists were, until recently, unable to impress the authorities with the importance and urgency of their work.

At the Geneva Conference[1] Polish scientists entered five papers and three of them were accepted for delivery at the conference. Prof. Niewodniczanski read a paper on Dr. Janik's work on the scattering of slow neutrons by chemical compounds; Prof. Soltan reported on the work initiated by Prof. Pienkowski and continued by his collaborators on Polish uranium ores and the presence of uranium in certain rocks; B. Buras read a paper on Polish research in the production of boron-free graphite of reactor standard, through the pyrolization of naphthalene. The papers not read at the Conference were Dr. Wilhelmi's on cross-sections of atomic nuclei and Dr. Jasinski's and Prof. Zlotowski's on limits of maximum irradiation intensity permissible for living organisms.

As in so many other countries, so in Poland the Geneva Conference brought about an intensification of research on nuclear physics and technology, and a determination "to make good our backwardness" (Prof. Infeld).[3] In August, 1955, the Institute of Nuclear Research (director: Prof. Soltan) was set up at the Polish Academy of Sciences; it now forms the centre of Polish work in the atomic field. A Committee on the Peaceful Uses of Atomic Energy, attached to the Praesidium of the Academy, was established at the same time. Its chairman is Prof. Infeld and its objects to plan and co-ordinate nuclear research, to co-operate in organizing training, and to publish a quarterly journal, *Nukleonika*.

On the government side, atomic affairs have, since July, become the concern of a Government Plenipoteniary for the Peaceful Uses of Atomic Energy. W. Billig has become the first holder of this office, whose chief function is the co-ordination of the work of government departments and the drawing up of a long-term atomic development plan for Poland. The Plenipotentiary will be assisted and advised by the Council for the Peaceful Uses of Atomic Energy.

The Nuclear Research Institute

Foremost among the problems which the Polish Academy of Sciences will pursue in the immediate future will be that of the peaceful uses of atomic energy. This was stated by Dembowski, the Academy's chairman, at its meeting in October, 1955. The Nuclear Research Institute, he said, would shortly become the Academy's largest institute, and its tasks would include large-scale research on the physics and technology of reactors, large scale production of radio-isotopes, designing prototypes of nucleonic instruments, research on the effects of ionizing radiation on the human organism and work in certain branches of medicine.

The Institute is now composed of two main centres: the Warsaw and the Cracow nuclear research establishments.

The Warsaw centre, also called the Central Polish Nuclear Research Establishment, is the successor to the research efforts previously dispersed among a number of Warsaw institutes. The centre will soon move to new premises on a site near Warsaw, where building work started in April and where the first laboratories, including the reactor block, are due to be completed by 1957. The Warsaw reactor will be of the same type as that offered by the Soviet Union in most of its other atomic assistance agreements, the light water moderated and cooled, 10% U^{235} enriched thermal reactor with a power rating of 2,000 kW. The technical data of this seemingly standard piece of Soviet nuclear research equipment were outlined by Nikolaev in the Geneva Conference paper P.622: "A 2,000-kW thermal power nuclear reactor for research purposes". The Warsaw reactor is expected to be completed in the middle of 1957.

On the same site a team of young Institute scientists under Prof. Keller recently began the construction of a medium-power (10-MeV) linear accelerator, to be completed in 1958. The machine will work as an independent nuclear research installation, but later on it will probably become part of a large accelerator whose construction is now under consideration. The 4-MeV Van de Graaff machine, just completed in Warsaw, also belonging to the Central Nuclear Research Establishment, is the first post-war all-Polish-built particle accelerator.

Cracow is Poland's second atomic research centre. The Cracow Nuclear Research Establishment (director: Prof. Niewodniczanski) is the successor of the Cracow Nuclear Physics Laboratory of the Polish Academy of Sciences' Physics Institute. The building of its new premises, including engineering, electro- and radio-technical workshops, began near Cracow at the end of 1955 and they are expected to be ready for occupation in 1957. The new premises will house the 25-MeV cyclotron whose delivery from the U.S.S.R. is to be completed in the winter of 1956-57. This large cyclotron, which will greatly enlarge the scope of basic research in nuclear physics, will work in conjunction with a small cyclotron of 4 MeV, designed and now being built in Cracow by a team of Polish specialists under Prof. Niewodniczanski.

Work on the construction of an electro-static generator of the Van de Graaff type producing 800 kV was concluded in Cracow in June, 1956. The building of this machine lasted four years and is also the work of Prof. Niewodniczanski's team. A large installation for magnetic nuclear resonance was earlier completed in Cracow, whilst a large spectrometer, based on scintillation counters, is also under construction. All this equipment will make it possible to conduct research on photonuclear reactions, which is of special interest to the Cracow centre.

Nuclear Power Prospects

Directives now published for technical research work in the 1956-60 Five-Year Plan ask Polish scientists and technologists "to master the technology and prepare the production of metallic uranium and of chemical materials required for this production" before 1960.[4] Admixtures of uranium and thorium have been found in Polish granites and phosphates, but it is not known whether their utilization is now contemplated. At any rate, Poland will not have metallic uranium on an industrial scale before 1960 and cannot contemplate an early nuclear power programme without having to import nuclear fuels.

In the past few months a discussion has been going on amongst Polish nuclear scientists, power engineers and economists about the desirability of an early start on the building of the first nuclear power station. Last spring a team of physicists and power engineers was formed at the Nuclear Research Institute and began studying plans for a possible atomic power station. In May a conference on this subject was held at the Institute,[5] but it apparently recommended against such an investment for the time being.

Certain Polish nuclear scientists[6] have argued that in the near future all states, irrespective of whether they have indigenous nuclear fuel sources, will have to take advantage of nuclear power if they want to remain abreast of technical progress and satisfy their economies' rapidly growing energy demands. Electric power consumption forecast for 1975 amounts to 140 thousand million units (see Table 1) and could hardly be met from hard-coal production alone. Provisional calculations have furthermore shown that an atomic power station would already pay its way in Poland, because the coal thus saved could be exported at very favourable prices. With Soviet help—but only with Soviet help, the scientists concluded—the first Polish nuclear power station could be completed by 1960.

TABLE 1—ELECTRIC POWER PRODUCTION
(Thousand million units sent out)

	1950	1955	1960	1965	1970	1975
U.K.*	52	73 (1954)		130		223
of which produced in nuclear plants					11-14	70-105
CZECHOSLOVAKIA†	9	15	25	40-45	60	80-100
of which produced in nuclear plants				5	20	40-60
POLAND‡	9	18	30			140

* "A Programme for Nuclear Power", Cmd. 9389, February, 1955.
† Directives for Second Five-year Plan, 1956-1960. Geneva Conference paper P/799, *Nova Mysl*, November, 1955.
‡ *Nowe Drogi*, June-July, 1956, *Przeglad Techniczny*, June, 1956.

These arguments seem to have been overruled on something like the following grounds: Poland has, as yet, no substantial production of her own nuclear fuels, but on the other hand, huge reserves of hard and brown coal. Investment in coal-fired plant is still cheaper than the large capital expenditure required for nuclear plants. The U.S.S.R., which would have to supply the power reactor, probably finds her resources strained as the result of her own atomic programme and the promises to Czechoslovakia, East Germany, Hungary and probably China. Finally, might it not be wise to wait a little longer until the most economic type of power reactor is more authoritatively determined?

For the time being the decision to build the first Polish nuclear power station has thus been postponed, the 1956-60 directives merely recommending the "carrying out of research into methods of gaining electric power by means of nuclear reactors".[4] But the same directives propose starting research on the "application of atomic energy to ship propulsion". Poland is, next to the Soviet Union, the most important shipbuilder of the Soviet bloc, planning to launch 200,000 tons in 1960. So far, 10,000-ton motor cargo-boats for the China route are the largest units built, but the building of a series of 18,000-ton tankers is to start soon. As for such large ships, nuclear propulsion is already held in the Soviet Union to be more economic than conventional propulsion, and since at present no other Soviet-bloc country seems to be building large merchant ships, Poland appears as the likely country to specialize in the building of nuclear-propelled merchant ships. At the moment, the Institute of Nuclear Research, the Maritime Institute and the Central Bureau of Ship Construction are jointly examining the economics of using nuclear propulsion for ships of the Polish merchant navy.

Organization of Training

Another interesting feature of Polish nuclear development is the comprehensive plan now being made for the training of undergraduates in nuclear engineering at Polish

universities and institutes of technology. Although their equipment may be used for purposes of instruction, the atomic research establishments will not themselves serve as training institutions.

Reporting in May, 1956, an expert committee specially appointed to consider this question concluded on the basis of what they have seen in the Soviet Union that training for work on the uses of atomic energy in Poland should comprise studies in three fields: nuclear physics, nuclear chemistry and nuclear power engineering. The study of these subjects will be organized at existing college and university faculties. Nuclear physics is to be taught at the Universities of Warsaw and Cracow, nuclear chemistry at the University of Warsaw —where the first department of Radio-chemistry in Poland has been working for some time under Prof. Zlotowski— and at the Wroclaw Institute of Technology, and nuclear power engineering at the Warsaw and Wroclaw Institutes of Technology. The Warsaw Institute of Technology will also train specialists in the application of automation to nuclear engineering. Students specializing in nuclear studies will have their normal degree course of five years extended by six months. The ablest students from all over the country will be enrolled for these studies. In the 1956-57 academic year, thirty students will take up nuclear physics at the physics and mathematics faculty of Warsaw University.

Training at Soviet Establishments

A certain number of scientists and technicians are now receiving training at Soviet nuclear establishments. Some fifteen members of the staff of the Nuclear Research Institute returned last spring from the Soviet Union, where they had received training in the operation of reactors. Six members of the Cracow research establishment had been instructed in the U.S.S.R. in working the large cyclotron purchased there. This summer some twenty more specialists left for various countries to increase their qualifications. After the Geneva conference the possibility was also mentioned of Poles receiving training in Britain.

As members of the Joint Nuclear Research Institute—the Soviet-bloc nuclear research organization situated in Kalininoblast, near Moscow, one of whose deputy directors, Danysz, is a Pole, and the other, Votruba, a Czech—Poland and Czechoslovakia have access to important research equipment, including two from among the world's largest particle accelerators.

Use of Radio-isotopes

Until the Polish reactor is working, radio-isotopes will be imported from the U.S.S.R. The first consignment of these arrived in August, 1955, and deliveries have continued since then.

Last spring agricultural research institutes, including a special isotope experimental station at Laskowice, near Wroclaw, began to use radio-isotopes in research on plant and animal metabolism and other problems, and have already had some results, particularly in the irradiation of maize seeds.

The training of medical specialists in the use of isotopes will be the function of a central isotopes institute of the Ministry of Health. The Institute for Supplementary Training of Physicians has been giving courses for doctors working in industries where isotopes will be used. For people working on isotopes, preliminary work-safety rules have been issued by the Ministry of Health. Next year, sections working with radio-isotopes will be set up at four medical research institutes and the Warsaw and Poznan Medical Academies.

Various institutes are becoming interested in the application of radio-isotopes in heavy industry. The Warsaw Electrotechnical Institute has trained a score of technicians in the use of radio-cobalt for investigating defects in metals. and before the end of the year it hopes to staff small isotope laboratories, each equipped with 0.5 g of radio-cobalt at two other institutes and seven large establishments of the engineering industry. The Institute of Metallurgy and others have begun work on the use of isotopes in investigating the purity of steel in furnaces. A new centre to conduct research on the application of isotopes is to be set up as part of the Institute of Fundamental Problems of Technology; this is to be greatly expanded after the commissioning of the Warsaw reactor.

References

[1] Lesz, M.: *Trybuna Ludu*, November 20, 1955, and *Gospodarka Planowa*, December, 1955; Kemula, M.: *Przeglad Chemiczny*, December, 1955.
[2] *Przeglad Geologiczny* for July, 1956, quotes the *Minerals Yearbook* for a 1951 Polish cadmium output of 240 tons.
[3] Interview with the Polish Press Agency, August 25, 1955.
[4] *Nowe Drogi*, June-July, 1956, pp. 249-50.
[5] *Trybuna Ludu*, May 20, 1956.
[6] Including B. Buras, the deputy director of the Nuclear Research Institute; see his article in *Przeglad Techniczny*, June, 1956; cf. also Ney, W.: *Przeglad Elektrotechniczny*, April, 1955.

L'Energie Atomique en Europe Orientale:
1ère partie—Pologne

L'Institut d'Etudes Nucléaires, fondé à l'Académie des Sciences de Pologne en Août 1955, *est maintenant le centre de tous les travaux polonais dans le domaine nucléaire, et possède des établissements à Varsovie et à Cracovie. Varsovie aura un réacteur d'études de* 2.000 *kW de l'U.R.S.S. et est aussi en train de construire un accélérateur linéaire de* 10 *MeV; un Van de Graaff de* 4 *MeV vient d'être terminé. A Cracovie un cyclotron de* 25 *MeV sera installé (il doit être livré par la Russie sous peu) tandis que des techniciens polonais viennent de compléter un générateur électrostatique de* 800 *kV et une installation de résonance magnétique nucléaire.*

Le dernier plan quinquennal envisage la production d'uranium métallique, l'etude des réacteurs d'énergie nucléaire et l'application de l'énergie atomique à la propulsion des navires.

Atomkraft in Ost-Europa:
Teil 1—Polen

Das Atom Forschungsinstitut, das von der polnischen Akademie der Wissenschaften eingerichtet wurde, ist jetzt die Zentralstelle für alle Arbeiten auf dem Gebiet der Atomtechnik in Polen; Arbeitszentren sind in Warschau und Krakau eingerichtet worden. Warschau wird einen 2.000 *kW Forschungs Reaktor von der U.S.S.R. erhalten, es ist weiter ein linearer* 10 *MeV Teilchenbeschleuniger im Bau; ein* 4 *MeV Van de Graaff ist gerade fertig geworden. In Krakau wird ein* 25 *MeV Zyklotron installiert werden (das von Russland demnächst geliefert werden soll), während polnische Wissenschaftler einen elektro-statischen* 800 *kV Generator und ferner eine magnetische Atom Resonanz Einrichtung fertiggestellt haben.*

Der letzte 5-Jahresplan sieht die Produktion von Uran Metall vor, Forschungsarbeiten in Bezug auf Reaktoren für die Krafterzeugung, schliesslich die Anwendung von Atomkräften für den Antrieb von Schiffen.

Energía Nuclear en Europa Oriental:
Parte 1—Polonia

El Instituto de Investigaciones Nucleares, que se estableció en la Academia Polaca de Ciencias en Agosto de 1955, *es ahora el centro de toda labor polaca en el campo nuclear, con establecimientos en Warsaw y Cracow. Warsaw tendrá un reactor de investigación de* 2.000 *kW desde la República Soviética, y también está construyendo un acelerador linear de* 10 *MeV; se ha completado recientemente un Van de Graaff de* 4 *MeV. En Cracow se instalará un ciclotrón de* 25 *MeV (a ser entregada próximamente por Rusia), mientras que los tecnicos polacos han terminado un generador electroestático de* 800 *kV y una instalación de resonancia magnética nuclear.*

El último Plan de 5-Años, prevee la producción de uranio metálico, investigaciones con respecto a reactores de potencia nuclear y la aplicación de la energía atómica a la propulsión de buques.

Unclear Times

INCORPORATING *The Harwell Examiner, Risley Non-Advertiser, Dounreay Sphere, Calder Hall Enterprise, Culcheth Enquirer, Berkeley and Bradwell Advocate, Windscale Sentinel, St. Giles Intelligencer and Parish Magazine.*

GLOSSARY OF TERMS

Specially compiled for the Uninitiated

Atom	Property of A.E.A.
Atomic	Non-U term for "nuclear".
Automatic scaler	Device for cleaning fish.
Background	Exclusive to Chalk River.
Barn	Hangar 10.
BeV	Proprietary liquid coffee.
Burst-slug detector	See **Salad days.**
Can	Portable responsibility.
Cladding	Protective clothing.
Compton scatter	Electron cover drive.
Consortia	Uneasy bedfellows.
Contamination	Un-occidental influence.
Control rod	Pole or birch.
Critical equation	A.E.A. + C.E.A. = . . .
Degradation	Applied research.
Diffusion plant	B.N.E.C.
Diffusion kernel	Army information officer.
Enriched	Gone into industry.
Enrichment factor	Development contract.
Epithermal	To do with the skin.
Excess reactivity	Projectless establishment.
Exposure	Work at Dounreay.
Feasibility study	Scheme for raising money
Fissionable	*A la mode*, chic.
Fission field	Winfrith Heath.
Fission spectrum	Billingsgate official.
Fluidized reactor	Ill-defined project.
Flux	Stage II design condition.
Half-life	35 years.
Head amplifier	Promotion.
Hole	Fault in construction.
Hole, experimental	Fault in design.
Health monitor	Factory inspector.
Isotopic tracer	Female draughtsman with a one-track mind.
Information, classified	May only be left in locked car.
Information, unclassified	May be left in unlocked car.
M.P.L.	Manchester Physical Laboratories.
Magic numbers	1 2 X.
Manipulator	Departmental head.
Monitor	International Atomic Energy Agency.
Phantom	See **Opera.**
Phase shift	Turning the other cheek.
Photomultiplier	Photographic enlarger.
Pile	A constraint of graphite.
Positronium	A musical instrument
Pseudoscalar	A musical instrument rather like an honorarium. which chang.s psign.
Quantum	Quorum of photons.
Rabbit	See **Power breeder.**
Radioactive family	The Groves.
Screening	Contamination detection.
Symposium	Drinking party (dict.).
Solvent extraction process	P.A.Y.E.
Thermal reactor	Gas-heated system.

Exchange Force

Pick-up Reaction

ATOMS AND THE CLASSICS

Research

Let Chymysts toil like asses. — *Beggar's Opera*
Imagineless metal, too costly for cost — *Francis Thompson*
Here's metal more attractive. — *Hamlet*
Savour of poisonous brass and metal sick. — *Keats*
No joy without alloy. — *Old Proverb*

Design

A breed for barren metal. — *Measure for Measure*
What's done we partly may compute. — *Burns*
Est modus in rebus (There is moderation in all things). — *Proverb*
Our little systems have their day. — *Tennyson*

Operation

And charge in earnest. — *Don Quixote (H. A. Dobson)*
The charge is prepar'd. — *Beggar's Opera*
A man ought warily to begin charges which once begun will continue. — *Francis Bacon*

. . . Fuel to maintain his fires
As old Time makes these decay . . . — *Thomas Carew*
All is gas and gaiters. — *Nicholas Nickleby*
Why it appears no other thing to me but a foul and pestilent congregation of vapours — *Hamlet*
Controls them and subdues, transmutes, — *William Wordsworth*
Make instruments to plague us. — *King Lear*
Will leave this to control. — *John Donne*
This shows how much easier it is to be critical than correct. — *Disraeli*

Safety

Lord, since thou knowest where all these atoms are, I'm hopeful thou'll recover once my dust. — *James Graham—Marquis of Montrose*
All thy friends are lapp'd in lead. — *Richard Barnfield*
Cool'd a long age in the deep-delved earth. — *Keats—Ode to a Nightingale*

Technical Writing

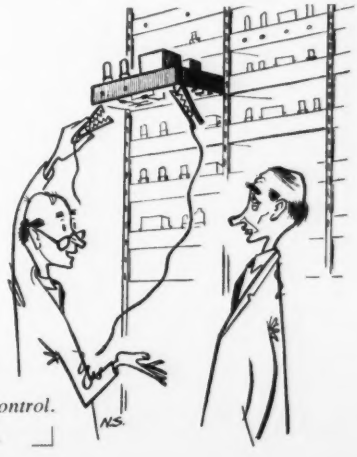
Golly, what a paper! — *R. L. Stevenson*
Good Lord, I'd rather be
Quite unacquainted with the A.B.C.
Than write such hopeless rubbish as thy worst. — *James Kenneth Stephen*
It is to be noted that when any part of this paper appears dull there is a design in it. — *Richard Steele*

Critical Assembly

This is the tale of Frederick Worms
Whose parents weren't on speaking terms
So when he wrote to Santa Claus
He wrote in duplicate because
One went to Dad and one to Mum
Each asked for some plutonium.
So Frederick's father and his mother
Each saying nothing to the other
Obtained a chunk of modest size
Intending it as a surprise.
They met in Frederick's stocking, and
Laid waste some ten square miles of land.
Learn from this tale of nuclear fission
Not to mix science and superstition.

(Courtesy *Chemistry and Industry.*)

'. . . but they got away with Borax'



When twins are born to a Harwell physicist he christens one and keeps the other for control.
B.N.E.C.

ON THE FEASIBILITY OF COAL-DRIVEN POWER STATIONS

By Professor O. R. FRISCH

THE recent discovery of coal (black, fossilized plant remains) in a number of places offers an interesting alternative to the production of power from fission. Some of the places where coal has been found show, indeed, signs of previous exploitation by prehistoric men who probably used it for jewels and to blacken their faces at tribal ceremonies.

The power potentialities depend on the fact that coal can be readily oxidized, with the production of a high temperature and an energy of about 0.0000001 megawatt-day per gramme. That is, of course, very little, but large amounts of coal (perhaps millions of tons) appear to be available.

The chief advantage is that the critical amount is very much smaller for coal than for any fissile material. Fission plants become, as is well known, uneconomical below 50 megawatts, and a coal-driven plant may be competitive for isolated communities with small power requirements or possibly for mobile units.

Design of a Coal Reactor

The main problem is to achieve free, yet controlled, access of oxygen to the fuel elements. The kinetics of the coal-oxygen reaction are much more complicated than fission kinetics, and are not yet completely understood. A differential equation which approximates the behaviour of the reaction has been set up, but its solution is possible only in the simplest cases.

It is therefore proposed to make the reaction vessel in the form of a cylinder, with perforated walls to allow the combustion gases to escape. A concentric inner cylinder, also perforated, serves to introduce the oxygen, while the fuel elements are placed between the two cylinders. The necessary presence of end plates poses a difficult but not insoluble mathematical problem.

Fuel Elements

It is likely that these will be easier to manufacture than in the case of fission reactors. Canning is unnecessary and indeed undesirable, since it would make it impossible for the oxygen to gain access to the fuel. Various lattices have been calculated, and it appears that the simplest of all—a close packing of equal spheres—is likely to be satisfactory. Computations are in progress to determine the optimum size of the spheres and the required tolerances. Coal is soft and easy to machine; so the manufacture of the spheres should present no major problem.

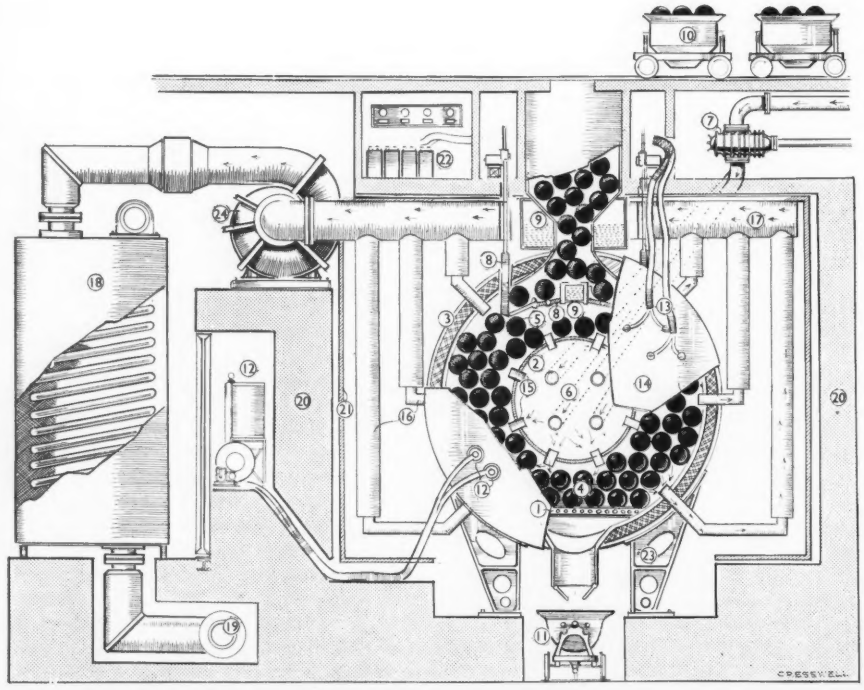
Oxidant

Pure oxygen is, of course, ideal but costly; it is therefore proposed to use air in the first place. However, it must be remembered that air contains 78% nitrogen. If even a fraction of that combined with the carbon of the coal to form the highly toxic gas cyanogen this would constitute a grave health hazard (see below).

To start the reaction one requires a fairly high temperature of about 988°F; this is most conveniently achieved by passing an electric current between the inner and outer cylinder (the end plates being made of insulating ceramic). A current of several thousand amps is needed, at some 30 V, and the required large storage battery will add substantially to the cost of the installation.

There is the possibility of starting the reaction by some auxiliary self-starting reaction, such as that between phosphine and hydrogen peroxide; this is being looked into.

Once the reaction is started, its rate can be controlled by adjusting the rate at which oxygen is admitted; this is almost as simple as the use of control rods in a conventional fission reactor.



KEY

1. Diagrid
2. Inner shell
3. Pressure vessel
4. Core lattice
5. Fuel elements
6. Inlet manifold
7. Control valves
8. Charge gate
9. Charge coolant
10. Charge machine
11. Discharge machine
12. Auxiliary chemical starting
13. Electrical starting
14. Ceramic end plates
15. Gas inlet
16. Gas outlet
17. Outlet manifold
18. Heat exchanger
19. To effluent plant
20. Biological shield
21. Thermal shield
22. Storage batteries
23. "A"-frame supports
24. Centrifugal blowers

Corrosion

The walls of the reactor must withstand a temperature of well over 1,000°F in the presence of oxygen, nitrogen, carbon monoxide and dioxide, as well as small amounts of sulphur dioxide and other impurities, some still unknown. Few metals or ceramics can resist such gruelling conditions. Niobium with a thin lining of nickel might be an attractive possibility, but probably solid nickel will have to be used. For the ceramic, fused thoria appears to be the best bet.

Mobile Units

One important advantage is the absence of penetrating radiation; hence the biological shield can be quite thin, as it merely has to absorb infra-red. Nor is the heat-exchange fluid likely to become radioactive; indeed, one might dispense with it altogether and place the reactor in direct juxtaposition with the steam-raising container, e.g., underneath it. The whole equipment thereby becomes so light that small mobile units become feasible. The well-known inventor, Trebor Nosnevets, has even suggested the use of coal power for operating a novel transport system which he thinks might relieve the present congestion of helicopters in small towns below 50,000,000 inhabitants. He envisages long chains of wingless fuselages resting on wheels (which run on steel rails to reduce friction and noise) and pulled by a single coal-powered tractor. Technically, the project appears feasible, but economically there are some doubts. Strips at least 300 ft. wide would have to be cleared of buildings and high walls erected on both sides as protection in case of a run-away reaction (see below). The steel rails would have to be ground to very close tolerances, and even so there are likely to be vibrations which would make travel in those contraptions unpopular. Also, the heavy advertising required to persuade people to try this form of travel may well put too high demands on our limited supply of commercial artists and social psychologists.

Health Hazards

The main health hazard is attached to the gaseous waste products. They contain not only carbon monoxide and sulphur dioxide (both highly toxic) but also a number of carcinogenic compounds such as phenanthrene and others. To discharge those into the air is impossible; it would cause the tolerance level to be exceeded for several miles around the reactor.

It is therefore necessary to collect the gaseous waste in suitable containers, pending chemical detoxification. Alternatively, the waste might be mixed with hydrogen and filled into large balloons which are subsequently released.

The solid waste products will have to be removed at frequent intervals (perhaps as often as daily!), but the health hazards involved in that operation can easily be minimized by the use of conventional remote-handling equipment. The waste could then be taken out to sea and dumped.

There is a possibility—although it may seem remote—that the oxygen supply may get out of control; this would lead to melting of the entire reactor and the liberation of vast amounts of toxic gases. Here is a grave argument against the use of coal and in favour of fission reactors, which have proved their complete safety over a period of several thousand years. It will probably take decades before a control system of sufficient reliability can be evolved to allay the fears of those to whom the safety of our people is entrusted.

"THEY"

The Song of the Theoretician

We're a bunch of back-room boffins, and we cannot see at all
Why we have to keep on thinking on the lines of Calder Hall
It is very unprogressive, and we find it really irks
To be told, when criticizing, "Yes, we know, chum—but it *works*".

CHORUS
Practicability! Practicability! That is the word today
Killing us with frustration, filling us with dismay
Why can't we win our freedom? Why can't we have our fling?
Never abstaining from constant maintaining
That Theory is ALWAYS King!

FIRST BOFFIN
Now I'm all for boiling water, and I really cannot see
Why they talk as though the thing were filled with conc. HNO_3
Water's beautiful in theory, and they always seem surprised
When I say it's *not* corrosive—only highly ionized.

CHORUS
Practicability! Practicability! Why can't they use some tact?
Stabbing a lovely theory—just for a *beastly* fact
Don't let your song be silenced! Let all your voices ring!
In measured diction, our solemn conviction
That Theory is ALWAYS King!

SECOND BOFFIN
Now organic moderation—ah, that really is the stuff
But when I propound my theory "rude mechanicals" get tough
(I consider it unseemly—not to say a bit obscene
When they talk of "degradation"—or even "Charleythene").

CHORUS
Practicability! Practicability! Lord how we hate the word
Why should "organic" create such a panic?—It really is too absurd
What if the moderator toasts to a lovely brown
Naught could be blander than our propaganda
Theory Wears the Crown!

THIRD BOFFIN
Now my ideal reactor runs on liquid-metal fuel
With uranium circulating in a semi-fluid gruel
All this talk about "mass transfer" leaves me feeling really sore
If the pipes get bunged up solid—what on earth are plumbers for?

CHORUS
Practicability! Practicability! This is the blooming end
Never mind the reactor—*we* are clear round the bend.
What if it needs a rock drill—or even dynamite?
Somebody boobs on the size of the tubes
Theory is Always Right!

FOURTH BOFFIN
We must push on with fast breeders—possibilities are vast
And for neutron economics they can hardly be surpassed
They are nothing but obstructionists, the folk who always say
Though the fission's fast and furious—you can't get the heat away!

CHORUS
Practicability! Practicability!—heat *always* dissipates
What do they think we are, chaps—perishing plumbers' mates?
What if it does get warmish—smothered in clouds of steam
Thermal equations in our calculations
Show Theory Reigns Supreme!

FIFTH BOFFIN
Why not make the gas cooled hotter? That should surely please them all
Those solid types who *have* to think in terms of Calder Hall
But of course there must be some small thing that fidgets and annoys
And it's open opposition from the metal-melting boys.

CHORUS
Practicability! Practicability! What are metallurgists *for*?
All that we're planning is metal for canning at four thousand F (or more)
Why do they moan that tungsten trickles around in drops?
Someone, I bet'll unearth a new metal
And Theory is still The Tops!

SIXTH BOFFIN
The homogeneous reactor heads my special merit-group
With its circulating fluid (what the U.S. calls the "soup")
But they say that it's corrosive—something more than troublesome
For it eats away the lining of the poor thing's little tum.

CHORUS

Practicability! Practicability! So little—yet so much
If they would only listen—why not the human touch?
Treat it like gastric ulcer. Use, to relieve the pain,
Anti-corroder, like bismuth (or soda)
Theory Scores Again!

SEVENTH BOFFIN

Now the liquid-metal graphite is the only one for me
Yet, though I preach it day and night, they never will agree
For they claim the graphite's porous—just as though it had a crack
And soon (if you'll forgive the pun) you'll find you've lost the NaK.

ALL

Well that is the position, and we really find it odd
The way the hardware merchants love the good old graphite-mod.
And all our sneers at "Model T" produce a judgment harsh
(Like Levassor's on the gearbox) *"Il est brutal—mais il marche"*.

FINAL CHORUS

Practicability! Practicability! How long must we submit?
Men without manners, with minds tuned to spanners—oh wouldn't it make you *spit*!
Let us be true to Theory—That, at least will endure
Leave all the panics to half-baked mechanics—Let Science be Always Pure!

(*Dance.*) **E.B.W.**

THE NEW SOURCE OF ENERGY

By H. G. WELLS

AND while the boy Holsten was mooning over his fireflies at Fiesole, a certain professor of physics named Rufus was giving a course of afternoon lectures upon radium and radioactivity in Edinburgh. They were lectures that had attracted a very considerable amount of attention. He gave them in a small lecture-theatre that had become more and more congested as his course proceeded.

"And so," said the professor, "we see that this radium, which seemed at first a fantastic exception, a mad inversion of all that was most established and fundamental in the constitution of matter, is really at one with the rest of the elements. It does noticeably and forcibly what probably all the other elements are doing with an imperceptible slowness. It is like the single voice crying aloud that betrays the silent-breathing multitude in the darkness. Radium is an element that is breaking up and flying to pieces. But perhaps all elements are doing that at less perceptible rates. Uranium certainly is: thorium—the stuff of this incandescent gas mantle—certainly is: actinium. I feel that we are but beginning the list. And we know now that the atom, that once we thought hard and impenetrable, and indivisible and final and—lifeless—lifeless, is really a reservoir of immense energy. That is the most wonderful thing about all this work. A little while ago we thought of the atoms as we thought of bricks, as solid building material, as substantial matter, as unit masses of lifeless stuff, and behold! these bricks are boxes, treasure boxes, boxes full of the intensest force. This little bottle contains about a pint of uranium oxide; that is to say, about fourteen ounces of the element uranium. It is worth about a pound. And in this bottle, ladies and gentlemen, in the atoms in this bottle there slumbers at least as much energy as we could get by burning a hundred and sixty tons of coal. If at a word, in one instant I could suddenly release that energy here and now it would blow us and everything about us to fragments; if I could turn it into the machinery that lights this city, it could keep Edinburgh brightly lit for a week. But at present no man knows, no man has an inkling of how this little lump of stuff can be made to hasten the release of its store. . . ."

The professor lifted his forefinger.

"Given that knowledge," he said, "mark what we should be able to do! We should not only be able to use this uranium and thorium; not only should we have a source of power so potent that a man might carry in his hand the energy to light a city for a year, fight a fleet of battleships or drive one of our giant liners across the Atlantic; but we should also have a clue that would enable us at last to quicken the process of disintegration in all the other elements, where decay is still so slow as to escape our finest measurements.

"I have no eloquence to express the vision of man's material destiny that opens out before me. I see the desert continents transformed, the poles no longer wildernesses of ice, the whole world once more Eden. I see the power of man reach out among the stars. . . ."

The problem which was already being mooted by such scientific men as Ramsay, Rutherford and Soddy in the very beginning of the twentieth century, the problem of inducing radioactivity in the heavier elements and so tapping the internal energy of atoms, was solved by a wonderful combination of induction, intuition and luck by Holsten so soon as the year 1933. From the first detection of radioactivity to its first subjugation to human purpose measured little more than a quarter of a century. For twenty years after that, indeed, minor difficulties prevented any striking practical application of his success, but the essential thing was done.

Holsten, before he died, was destined to see atomic energy dominating every other source of power, but for some years yet a vast network of difficulties in detail and application kept the new discovery from any effective invasion of ordinary life. The path from the laboratory to the workshop is sometimes a tortuous one; electromagnetic radiations were known and demonstrated for twenty years before Marconi made them practically available, and in the same way it was twenty years before induced radioactivity could be brought to practical utilization. The thing of course was discussed very much, more perhaps at the time of its discovery than during the interval of technical adaptation, but with very little realization of the huge economic revolution that impended.

It was in 1953 that the first Holsten-Roberts engine brought induced radioactivity into the sphere of industrial production, and its first general use was to replace the steam engine in electrical generating stations. Hard upon the appearance of this came the Dass-Tata engine—the invention of two among the brilliant galaxy of Bengali inventors the modernization of Indian thought was producing at this time—which was used chiefly for automobiles, aeroplanes, waterplanes and such-like mobile purposes. The American Kemp engine, differing widely in principle but equally practicable, and the Krupp-Erlanger came hard upon the heels of this, and by the autumn of 1954 a gigantic replacement of industrial methods and machinery was in progress all about the habitable globe. Small wonder was this when the cost, even of these earliest and clumsiest of atomic engines, is compared with that of the power they superseded.

* * *

These extracts are taken from *The World Set Free*, a "fantasia of possibility" written by that remarkable explorer of the future and of the realms of fancy, H. G. Wells, in 1913. They are reprinted by permission of H. G. Wells' executors. In a preface, dated 1921, to the edition published by Odhams Press Ltd., Wells confessed that, as a prophet, he had always been inclined to be rather a slow prophet and that the misses in the story far outnumber the hits—but that does not alter the fact that his forty-year-ahead (1953) forecast of the first nuclear power station was not very far off the mark.

Industrial Enterprise

Development and Production at the Renfrew Works of Babcock and Wilcox Ltd.

ON November 9 the Renfrew works of Babcock and Wilcox Ltd. were thrown open to the technical Press, who were able to examine the conventional steam-plant manufacturing capacity, the heat-exchanger assembly lines for Calder Hall and Chapel Cross and the research laboratories, where an extensive programme is under way to examine future possibilities of nuclear power. As far back as 1947, preliminary work was started on the problems to be encountered in raising steam from the heat liberated in a nuclear reactor, and at the beginning of this month a special section was formed under the previous chief research engineer, Mr. T. B. Webb, who now becomes the manager of the company's Atomic Energy Department.

The activities of the company in conventional plant manufacture and development are well known, and at the Scottish works, plant has already been laid down for the handling of exceptionally-thick sections and for the fabrication of unusually-heavy vessels. Testing facilities include a 2-MeV X-ray machine for the rapid examination of large pressure vessels, and considerable attention has been devoted to the use of ultrasonic techniques for the examination of butt welds. Transportable equipment has been devised for the examination on site of butt welds using two angled transducers, one transmitting and one receiving, mounted on an articulated roller-bearing demountable band. The signal from the receiving quartz is viewed on a C.R.O.

Looking down the assembly line for the heat-exchanger shell sections. The internal bracing prevents distortion.

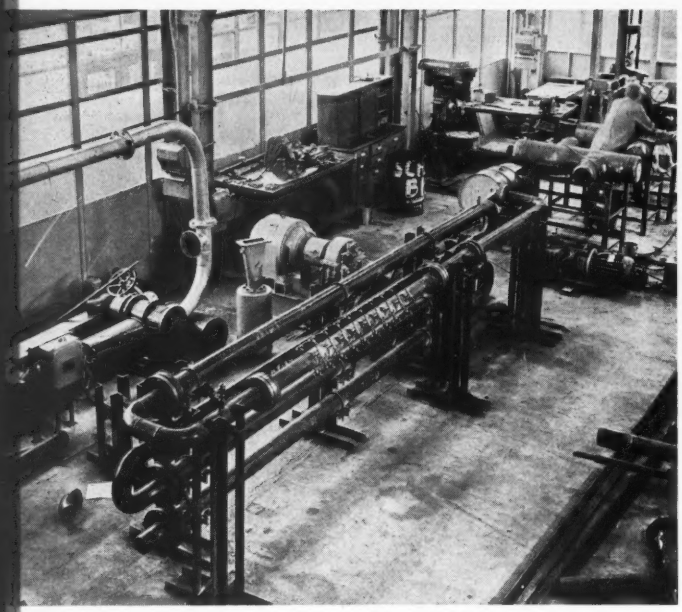
High Pressure Vessels

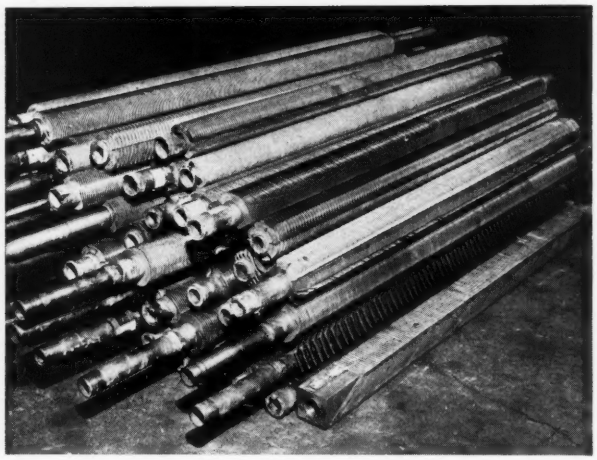
A 2,000-ton press has considerably facilitated the bending of the Calder-type heat-exchanger vessel sections and this has been designed to accommodate steel thicknesses up to a maximum of 8 in. and can, therefore, be of considerable importance if developments on water-moderated reactors proceed. The first use to which this press has been put in this direction is for the N.P.D. pressure vessel, an order for which was received by Babcock and Wilcox in June of this year. This is the first construction of its type in the Commonwealth. The pressure vessel is of mild steel 5 in. thick, increasing to 6½ in. in some parts. It will stand 35 ft. high and 12 ft. in diameter and will weigh 20 tons, of which 10 tons is in the head section, a very massive structure which bolts to the main body to allow complete access. The head is further pierced by a large number of tubes for control rods, etc., each with individual closure. The vessel is cladded internally with stainless steel welded into position after completion of the pressure shell. Because of the unknowns in the design of such a vessel, B. and W. have suggested that a half-size model should be built to confirm as much as anything that the access requirement demanded can be met in practice. A complete programme of testing to destruction on vessels of this thickness is also envisaged.

Heat exchangers for both the "A" and "B" stations at Calder Hall have now completed their shop fabrication and work is in hand on the Chapel Cross contract. It is expected that delivery will be at the rate of one per month until the order for 32 has been completed. Manufacture of these vessels, which, when erected are 17½ ft. in diameter and 77 ft. high, is now performed on a production-line basis and little evidence remains of the considerable development that was required to organize this. The heat-transfer elements in these vessels consist, except in the superheater sections, of studded tubes requiring the welding of 10.7 million oval-section studs per heat exchanger. This is performed semi-automatically by a resistance welding process. At present the studs are fed into the hollow electrodes by hand, having previously been cut accurately to length, but an automatic feed is under development. Initially, tube-sections were all hydrogen leak-tested, but as no faults were found a 10% sample only is now tested. After pumping down to 4 microns, the section is enclosed in a plastic cover and hydrogen is then fed in whilst a Pirani gauge monitors the vacuum system.

Research

The research and development department, situated some distance from the main works, is steadily expanding and at present consists of over 270 personnel. A section has been set up for spectographic examination, using both solid and liquid samples, and investigations have included Magnox and other magnesium alloys, aluminium alloys, steels and graphite. Tests on graphite have indicated that a number of reactor-grade graphites are available and that virtually pure graphite can be formed by passing a heavy current through the manufactured blocks. It is expected that work on zirconium alloy will begin in the near future and samples of Zircalloy have been received from the American counterpart company.





A selection from the 300 brass cans used for rapid sorting of fuel-element shapes.

(Left). Test rig for fuel cans in a CO_2 atmosphere at 150 p.s.i. and 400-450°C. Spiral electrical elements generate 15 kW/ft. heat.

A Ferranti Pegasus electronic computer is to be installed at the head office building in London to allow an expansion of the work that has already been done on the behaviour of reactor systems under transient conditions.

A wide range of compatibility trials is being conducted at Renfrew, including the behaviour of various materials in a CO_2 atmosphere at a pressure of 150 p.s.i. and a temperature of 400-450°C. Work, however, is not being confined to CO_2 compatibility, and for some time there has been considerable interest in the compatibility problems associated with the use of water in a reactor. Liquid-metal reactor systems are also undergoing a similar investigation.

The effect of temperature cycling on canned fuel elements is considered to be of considerable importance and plant is in operation for the investigation of the ratcheting effect of uranium in a Magnox can.

The design of conventional high-temperature steam-raising plant requires data from hot rupture tests only, as permanence of dimensions is not of primary importance. In reactor work, creep strain is of considerable importance and at present 24 creep-testing machines are in operation and this number is to be increased.

A considerable programme of work has been initiated for the examination of the heat-transfer characteristics of various geometrical shapes. A quick sorting rig has been set up in which representative cans made of brass are steam heated in a long, cylindrical vessel through which air is circulated at nearly atmospheric pressure. Measurements are then made of the pressure drop along the can and of the heat-transfer characteristics. About 300 different designs have been tested in this way and it is interesting to note that, whilst no satisfactory theoretical estimation has been forthcoming of the properties of the designs, operators are able to make a fairly accurate guess at their behaviour. Likely designs are to be tested in a rig which simulates reactor conditions in terms of coolant-gas pressure and temperature. Magnesium alloy cans are anodized to a depth of 4 to 8 thou on the inside and a close-fitting spiral element is inserted which is electrically treated. Ratings of 15 kW/ft. have been achieved. It is understood that, whilst tests have not yet been completed, the preferred can for the C.E.A. stations will differ considerably from the Calder Hall type. Similar types of experiment have been conducted on heat-exchanger element surfaces and it is probable that some change in these will also take place. An examination has also been carried out of the theoretical implications of increasing outlet gas temperature from a gas-cooled reactor and these indicate that a marked advance in exit gas temperature would imply a multi-pressure cycle on the steam side.

As a further indication of the interest of B. and W. in the water-moderated and cooled reactor, a loop is under construction for the U.K.A.E.A. for insertion in DIDO to carry out high flux corrosion tests of light water in typical constructional materials.

Jig for ultrasonic testing of butt welds.

Problems of Liquid-Metal-Fuelled Reactors

by
B. R. T. FROST, B.Sc., Ph.D.
A.E.R.E., Harwell

PART 2

The problems associated with bismuth circuits are not so well understood as those involving sodium. Suggested bismuth L.M.F.R. systems are discussed with reference to mass transfer, penetration and corrosion of graphite and suitability and corrosion behaviour of constructional materials.

BASICALLY, only two liquid metals are of interest at present as fuel and blanket media for L.M.F.R. systems: sodium and bismuth. The technology of sodium has been studied so extensively in the U.S.A. and in this country that the selection of container materials and the design of circuits present few difficulties. Such problems as do arise usually originate from the presence of oxygen in the sodium (e.g., in the zirconium canning of graphite in the N.A.A. reactor).[10]

There are, on the other hand, so many new features in the bismuth system that this section will deal specifically with this subject. Physics calculations have shown that a thermal reactor can be made to operate on a solution of 600-700 parts per million (by weight) of pure U 233 or U 235 dissolved in bismuth.[2] This represents a lower temperature limit of about 320°C (Fig. 1). The core size for such a system using graphite as moderator is approximately a 5-ft. right-cylinder with a U-Bi to graphite volume ratio of 1:1. For a beryllium-moderated system the core size will be somewhat smaller. A power reactor of these dimensions generating 500 MW produces a flux of 10^{15} n/cm²-sec. in the core. To remove this heat the liquid must flow through the core and out to heat exchangers at the rate of 36,000 g.p.m. In practice, the blanket will contribute up to 25% of the heat output. This blanket consists of an annulus 3 to 4 ft. thick surrounding the core vessel containing a suspension of Th_3Bi_5 in bismuth. It also contains graphite to moderate epi-thermal neutrons leaving the core and has a separate coolant circuit. The whole of this is enclosed in a steel vessel 12 ft. in diameter and 15 ft. high, to which are attached the inlet and outlet pipes to the heat exchangers and processing plant. Performance figures were given in Table 2 in Part 1 (November, 1956).

An interesting variant of the uranium-bismuth-fuelled system has been described by Teitel.[11] This is an internally cooled 500-MW (heat) reactor using a dispersion of UBi_2 in a bismuth alloy as the fuel, the concentration of uranium being 0.7% (7,000 p.p.m.). The core is cooled by the Th_3Bi_5-Bi dispersion which passes through graphite channels in the core and out to primary heat exchangers, made of a 5%Cr, 1% Si steel, which are located within the 24-ft. diameter reactor vessel. The calculations predict a doubling time of 3.6 years and a specific power of 4.50 kW per gm of U 233, assuming a total investment of 110 kg. The chief criticism of this system is the use of "reactive" slurries which are circulated through quite large temperature gradients (the breeder-coolant dispersion upper and lower temperatures in its circuit are 520° and 350°C respectively). It can only be hoped that the fission and decay heats and the fairly rapid flow rates are sufficient to overcome the mass-transfer tendencies of this type of slurry.

The chief materials problems arising from such designs are twofold:

(i) is graphite attacked or permeated by the core solution or by the blanket slurry; and

(ii) what readily available, cheap materials can be used for the remainder of the structure?

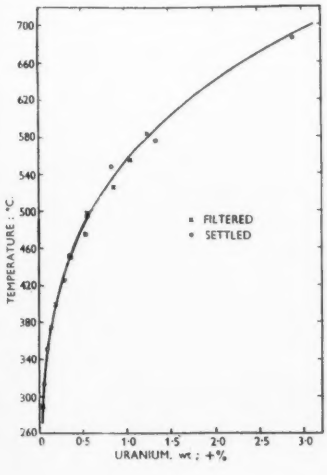


Fig. 1 (left). Solubility curve for uranium in bismuth.

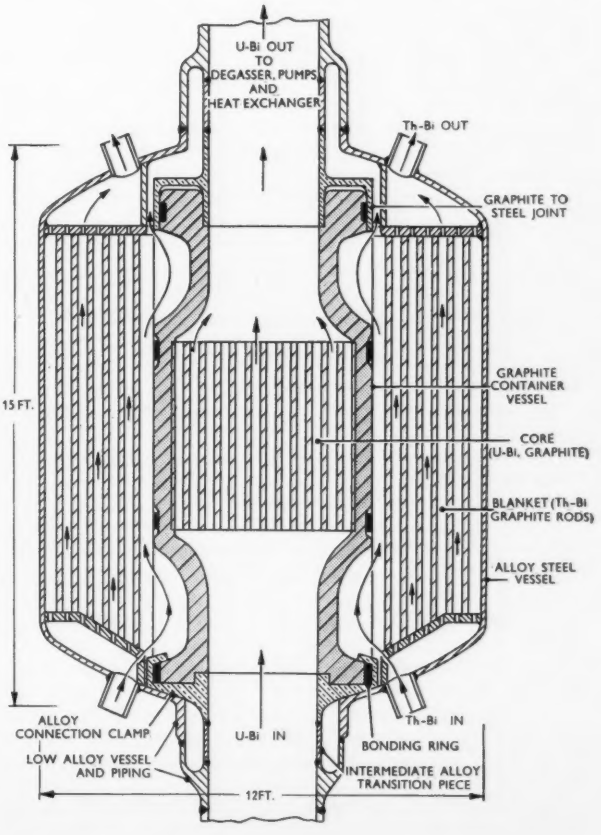


Fig. 2 (right). Vertical section of the reactor vessel for the B.N.L.'s L.M.F.R. system.

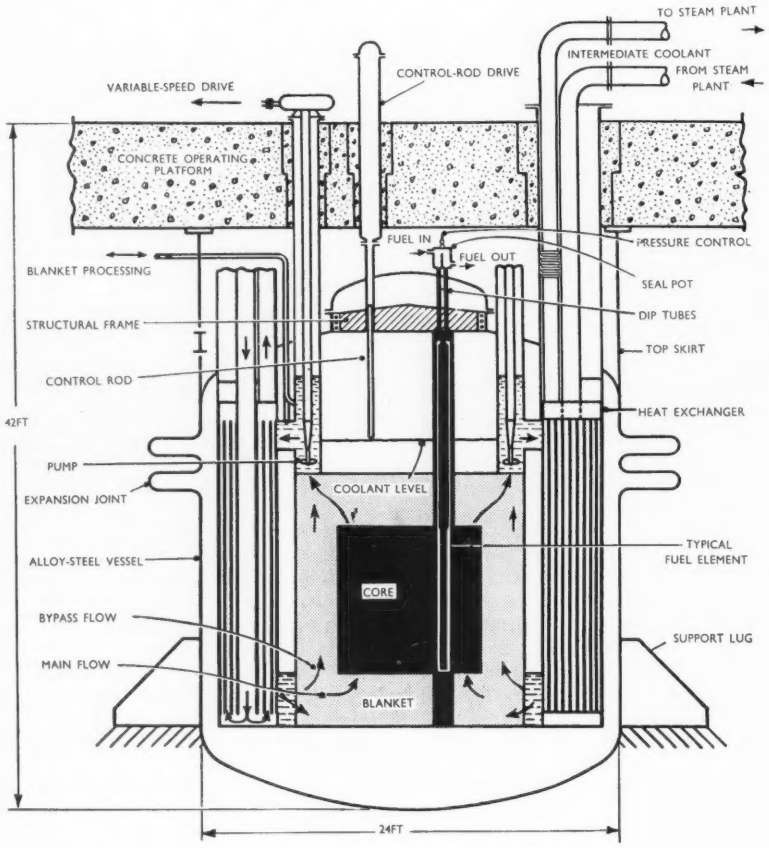


Fig. 3. Suggested internally-cooled 500-MW (heat) reactor using a dispersion of UBi_2 in a bismuth alloy as the fuel.

changes only very slowly with temperature, so isothermal mass transfer of carbon to steel as observed in sodium systems[10, 11] is most unlikely to occur. It is clear that, provided the graphite is impregnated or of a high density, it is quite compatible with the fuel and need not be protected by canning or coating. This material is probably more susceptible to erosion and cavitation effects than metals, so high flow rates may not be permissible with a heavy metal like bismuth. There is at present, however, no scientific basis for fixing an upper limiting flow velocity, but B.N.L. has selected 10 ft./sec. from a conservative estimate.

Similar arguments apply in the case of the blanket as far as carbide formation is concerned. The erosive nature of the particles may call for a reduction in flow rate, but in any case the fission density is less than in the core and high flow rates to extract heat are not necessary.

Graphite Moderator

It will be appreciated from Fig. 2 that the graphite in the core vessel will be subjected to a hydrostatic pressure of bismuth which may be as high as 200-300 p.s.i. in places. Thus, although the surface tension of bismuth is more than twice that of sodium at the same temperature, there is some tendency for penetration into the graphite. This can be overcome by impregnation of the graphite; B.N.L. uses a product known as "graph-i-tite", made by Graphite Specialties of Niagara Falls, N.Y., which is impermeable to bismuth. The problem then resolves itself into the development of techniques for the fabrication or assembly of this material on the scale and in the shapes required. Miles and Williams[2] describe a method of assembling staves of graphite to form a barrel which is clamped by alloy bonding rings. It has also been reported that American graphite producers can make blocks of the required size in one piece. These could be machined to provide the fuel passages.

Assuming the fabrication problems can be overcome in time, the question remains of whether the fuel will react with graphite. The answer is that it has been shown by experiments at Brookhaven to be most unlikely. In solutions containing less than 1% (10^4 p.p.m.) U, the uranium and graphite do not react to form uranium carbide, UC, until over 1,000°C. At higher concentrations reactions can be observed at 1,100°C, but even this can be stopped by the presence of inhibitors in the liquid. These inhibitors are added mainly to protect the steel from corrosion and are discussed at length below. One of these additions is zirconium, which forms a very stable carbide, ZrC, on the surface of graphite. This surface layer prevents the formation of UC at temperatures well above 1,000°C and is believed to discourage fission-product adsorption.

The solubility of carbon in bismuth is very low at normal power-station steam temperatures (2.5 p.p.m. at 550°C) and

Metallic Containers

In the selection of container materials for bismuth, valuable information has been derived from investigations which were not concerned specifically with L.M.F.R. requirements. Experience in the bismuth smelting industry and some general investigations on heat-transfer fluids form the basis of the information in the *Liquid Metals Handbook*[14] in which the unsuitability of nickel-bearing steels and non-ferrous alloys is mentioned. More recent work by Elgert and Egan,[15] Cygan,[16]

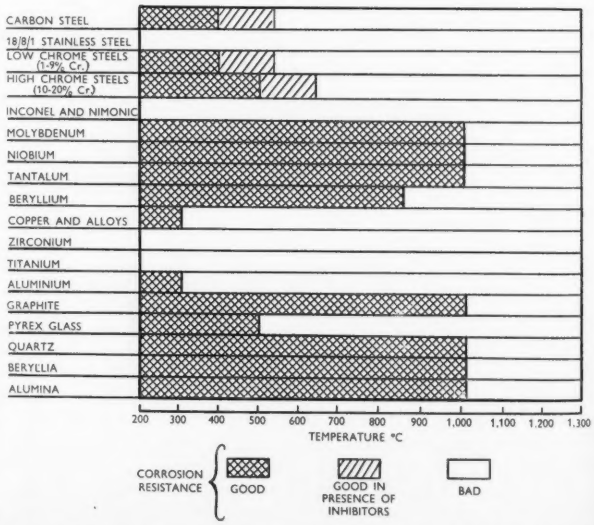


Fig. 4. Compatibility of metals and non-metals with molten bismuth.

of North American Aviation, Wilkinson[17] of the Argonne National Laboratory, and Eldred at Cambridge University, Metallurgy Department,[19] has given detailed information on the corrosion behaviour of metals and ceramics in bismuth up to high temperatures and a fairly complete list is available (Fig. 4).

It will be seen that the ferritic steels are fairly resistant to attack, which accords with experience with other heavy metals, in particular with the work on the General Electric Company's mercury boiler.[18] In that case it was found that the ferritic steels were satisfactory under isothermal conditions, but a temperature gradient led to fairly rapid corrosion.

This is the phenomenon of temperature-gradient mass transfer which is of importance in all liquid-metal systems and, since it is of considerable importance in the present context, it will be discussed in more detail.

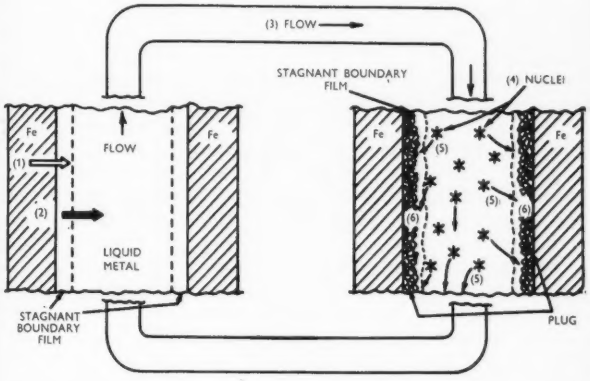


Fig. 5 (above). Schematic diagram, illustrating mass transfer.

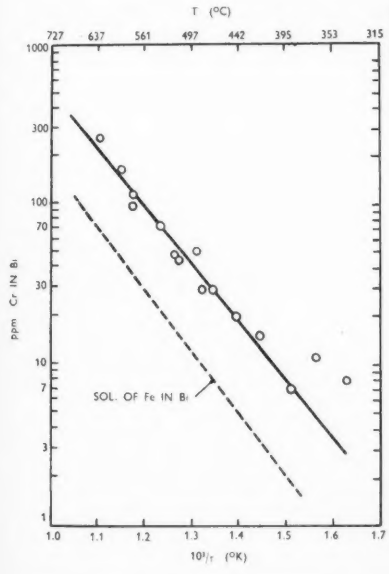


Fig. 6 (left). Solubility of iron in bismuth compared with that of chromium in bismuth + 500 p.p.m. Mg.

The curve in Fig. 6 represents the solubility of iron in bismuth. At about 470°C the solubility is 10 p.p.m. and at 560°C it is 30 p.p.m. If bismuth were pumped round a pure iron loop, one side of which was at 560°C and the other side at 470°C, at such a velocity that equilibrium solubilities could always be approached, the liquid would be saturated at 30 p.p.m. Fe on the hot side and supersatured by a factor of three on the cold side. Under these conditions, precipitation of the excess iron would occur until the solubility of 10 p.p.m. was reached. This liquid would then be unsaturated on arrival at the hot side and would dissolve more metal and so on. It is easy to see that, even at such low solubility values, the transfer of iron can cause rapid thinning of the hot wall

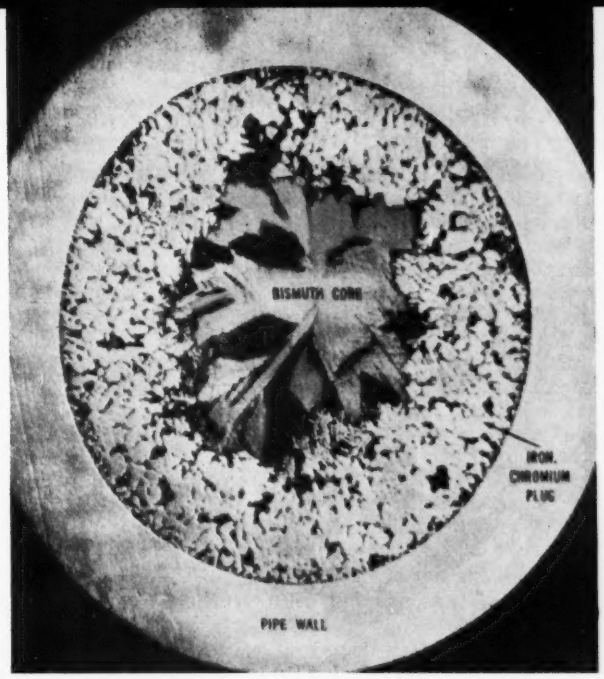
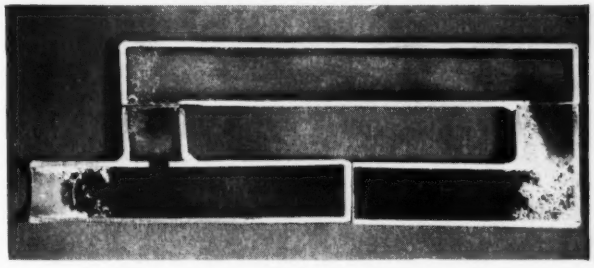


Fig. 7 (above). Typical plug caused by the transfer of iron from the hot end of a pipe to the cold. Fig. 8 (below). Small convection loop constructed of $2\frac{1}{4}\%$ Cr and 1% Mo steel. Note plug at coldest part (450°C) on right, and removal of material from hottest part (550°C) on left. (From the work of G. W. Horsley, A.E.R.E., Harwell.)



and formation of a plug on the cold (Fig. 7). These idealized conditions do not obtain in practice due to the rapid flow rates employed, but they are certainly approached. Fig. 8 shows the hot and cold limbs of a thermal convection loop which ran at temperatures of 550° and 450°C respectively. Flow in this loop ceased due to the plug formation after 150 hours.

This problem taxed the General Electric Company (U.S.A.) for a long time before the answer was obtained. It was found that the addition of certain metals, particularly titanium and zirconium, reduced the rate of mass transfer very drastically. Elgert and Egan tried the same technique with bismuth, adding magnesium and titanium, with marked success. It was found to be necessary to add the magnesium first, or at least at the same time as the titanium, otherwise the latter is oxidized and inhibition is not effective.

In the subsequent work at B.N.L. zirconium was added in preference to titanium, as the former has better nuclear properties and, being a fission product, there is a small but steady addition under reactor conditions. By an admirable piece of research,[20] it was shown that the zirconium (or titanium) in both the mercury and the bismuth systems inhibited the corrosion by formation of a film of zirconium nitride, ZrN, a very stable compound. This is formed at the interface between the liquid and solid by reaction between the zirconium in solution in the liquid and nitrogen in the steel. The best confirmation of this mechanism was the failure of zirconium to inhibit corrosion of an iron pot which had been made by vacuum melting to remove the dissolved gases, including nitrogen. This is, however, not the whole story because the nitride layer does not prevent nickel from getting into solution in the bismuth. Moreover, it seems to be neces-

sary to impose an upper limit of 150°C on the gradient and of less than 600°C on the highest temperature for long-term operation of the inhibitors.

Work at Brookhaven indicates that the inhibitors play some part in arresting precipitation at the cold side of a system. It is conceivable that nucleation and growth of the particles, or even their adhesion to the walls, is affected by changes in interfacial tension brought about by zirconium, which is a surface-active element. Such postulations will only be confirmed or disproved after a further period of difficult research. If the complete picture of the inhibiting mechanism were available it would be easier to predict the effects of irradiation on corrosion. As it is, no clue will be obtained until in-pile experiments have been performed. It seems probable that the fission-fragment bombardment of the nitride layer will be the main source of danger and the three questions to be answered in this investigation are:

(i) is the nitride film disrupted; if so

(ii) does the film heal sufficiently rapidly to combat this effect,

(iii) on what factors does film repair depend, e.g., are both the nitrogen content of the steel and the zirconium content of the bismuth important?

It would be rash to make predictions and one should not draw too close an analogy with the H.A.R. system, in which the corrosion resistance is very much altered at high fission densities, particularly as it is probable that the protection in the L.M.F.R. case is not entirely dependent on the nitride film. It should also be realized that the only material likely to be in contact with the fuel at the maximum flux is the moderator, and that the flux at the heat exchangers and pumps may be considerably below the peak value.

One may be tempted to think that the degree of reliance which has to be placed on "a pinch of salt", added to the fuel for long reactor life, is far too high for safety. In point of fact, this system is no more finely balanced than the standard high-temperature steam boiler or superheater where the presence or absence of a few parts per million of chlorine can spell disaster or success as far as corrosion behaviour is concerned. There are many other examples of commercial practice, even the G.E. mercury boiler itself, where long experience has led to confidence in these techniques and there is no reason to expect the L.M.F.R. to be different in this respect, provided that the stipulated running conditions are adhered to and the system is kept as leak-tight as any other liquid-metal circuit.

It was noted earlier that certain metals are strongly resistant to liquid bismuth, even at temperatures as high as 800°C. These metals, which include molybdenum, niobium, tantalum, tungsten and beryllium, may be considered for use in two circumstances: first, if the inhibiting layer should be susceptible to enhanced attack under irradiation; and, secondly, in a high-temperature (perhaps gas-turbine) application. Beryllium is particularly attractive, since its moderating properties lead one to consider an internally cooled thermal system with a low investment, high thermal efficiency and considerable safety. One would also expect less trouble from fission-product adsorption than when using graphite as the moderator. There are, however, a few problems to be solved before such schemes can be realistically assessed.

In the first place none of these metals is particularly easy to fabricate and, in fact, it is only the intense interest from the atomic-energy field and the consequent research and development programmes which even allows us to consider these metals for such applications. It is now well known that beryllium, niobium, molybdenum and tantalum can be produced in tubular form and that limited success has been obtained in their welding, particularly of Nb and Ta, but the development of this latter technique is at present the main limiting factor in their use.[21] It is possible that in some applications ingenuity of engineering design may minimize these difficulties but will never eliminate them. There is, however, every hope that complete success in fabrication will be obtained in the near future.

In addition, the cost of these materials is high. However, compared with the total cost of the reactor, some latitude is allowable in the capital cost, particularly if thermal efficiencies are thereby enhanced.

Another factor which is at present being studied is the extent to which uranium in solution in bismuth will react with these metals at 800°C. It is known that uranium will alloy with all the elements listed, but inter-diffusion at 800°C is usually very slow and when the uranium is dispersed in a dilute solution it will probably be even slower. However, the consequences of fission occurring in the bulk of the container material with build-up of fission products are sufficiently unpleasant to justify work to discover whether these diffusion effects are likely to occur.

For certain applications in the L.M.F.R. system special properties may be required of materials, e.g., the channels of electro-magnetic pumps must not provide a low resistance path for the current which would otherwise pass through the liquid bismuth, and so high resistivity steels, such as 12% chrome, must be considered. In addition, the chemical-processing plant will be required to withstand attack by a variety of materials, particularly molten salts. As this part of the plant will most probably be held at a constant temperature, nickel-bearing steels might be contemplated although, in general, the high chromium, nickel-free steels are preferable for this purpose.

Another aspect which must be borne in mind when choosing heat-exchanger materials is the nature of the secondary coolants, which may be one of the many heat-transfer media used in reactor technology including gases and liquid metals. For compactness of the primary heat exchangers, a liquid metal is preferable. A survey quickly reduces the possibilities to sodium (or NaK), lead-bismuth eutectic or bismuth. None of these coolants attacks inhibited low chromium steels at 550°C, so the choice of heat-exchanger material is simple. However, one must also make quite sure that the heat exchanger is 100% reliable, either by the use of a double

Problèmes soulevés par les Réacteurs à combustible métal liquide.

Seuls deux métaux liquides présentent actuellement de l'intérêt en tant que moyens combustibles et de couverture pour les systèmes L.M.F.R. (Liquid Metal Fuel Reactor) de réacteur à combustible métal liquide: le sodium et le bismuth. Alors que l'on a une somme considérable de connaissances sur la technique du sodium, les problèmes se rapportant aux circuits de bismuth sont moins bien compris. Cet article, en conséquence, est consacré à un examen du problème bismuth.

Un L.M.F.R. thermique nécessite une concentration minimum de U 233 ou U 235 purs dans le bismuth de 600 p.p.m, ce qui pour des considérations de solubilité implique une température minimum de 320°C. La grandeur de noyau pour une telle concentration serait d'environ 1,50 m. par 1,50 m., en contenant des volumes égaux de U.Bi et de graphite. Si de la chaleur était produite à 500 MW, le débit liquide requis serait de 163.550 litres par minute. Les couvertures d'une épaisseur de 90 cm. ou 1,20 m. contiendraient probablement une suspension de Th_3Bi_5 dans le bismuth.

Une forme de L.M.F.R. suggérée utilise une dispersion de U.Bi en un alliage de bismuth mais les problèmes de transfert de masse ont de grandes chances de se poser sérieusement. Cet aspect est discuté assez détaillément. D'autres problèmes de nature sérieuse se rapportent à la pénétration et à la corrosion du graphite qui peuvent être réduites au minimum par l'impregnation et l'introduction d'inhibiteurs.

Les aciers ferritiques conviennent généralement comme matériaux de construction pourvu que les inhibiteurs appropriés soient employés, tels que le zirconium que l'on croit former une mince pellicule de ZrN. D'autres métaux tels que le niobium, le molybdène, le tantale, le tungstène et le béryllium conviennent aussi et portent la température de fonctionnement jusqu'à 800°C.

TABLE 1—THE PRESENT STATE OF KNOWLEDGE ON THE L.M.F.R. SYSTEM

CREDIT	DEBIT
(1) We know the solubility curves and alloying characteristics of U, Th and Pu in bismuth.	(1) The effect of irradiation on the corrosion inhibition technique is unknown.
(2) We know which steels and what type of graphite are suitable for containing U-Bi fuel solution under inactive conditions.	(2) The Th_3Bi_5-Bi slurry has not yet been pumped round an isothermal loop, let alone a temperature-gradient loop.
(3) A fairly comprehensive scheme for removal of fission products from the fuel has been drawn up and tested by an in-pile experiment at Brookhaven.	(3) The adsorption of fission products on graphite from U-Bi fuel has not been carefully examined.
(4) Bismuth and U-Bi fuel have been pumped by mechanical and electromagnetic pumps.	(4) The chemical behaviour of polonium in the system is not known, e.g., it may form polonides with uranium or thorium.
(5) Th_3Bi_5-Bi slurries have been prepared and a few of their properties studied. Processing experiments have been performed on irradiated slurries.	(5) There is no wholly satisfactory process for the separation of U 233 from the blanket.

annulus form of construction or by very careful fabrication and inspection methods, since leakage of the coolant into the core fluid or vice versa would call for an immediate shutdown. In the case of sodium the consequences could be serious, for it is known that sodium and bismuth react with one another to form intermetallic compounds with considerable evolution of heat. Therefore it is probably safest to suffer the somewhat inferior heat-transfer properties of lead-bismuth eutectic or of bismuth. On the other hand, with the cost of bismuth at £2,000 a ton, any saving on its investment should be encouraged. Moreover, the transfer of the polonium hazard, albeit on a reduced scale, to the secondary coolant circuit represents an unpleasant feature.

In the design and operation of bismuth circuits it must always be remembered that bismuth is one of the few metals which expands on freezing (by about $3\frac{1}{2}\%$) and uncontrolled freezing can lead to rupture of pipes. Ideally, the metal, once in the reactor, should never be allowed to freeze and indeed after the reactor has run for a short while the heat produced by γ capture and Po 210 decay should suffice to keep the metal molten for a long time.

From this survey one can draw up a profit-and-loss account for the L.M.F.R. system and see where the weak points, which need strengthening by further experimental work, lie. These are listed in tabular form in Table 1, from which it can be seen that the main gaps in our knowledge lie in our ignorance of the behaviour of metallic slurries and in the lack of experience of the chosen combination of materials under high flux irradiation conditions.

Both these weaknesses are the subject of intensive effort on both sides of the Atlantic at present, and one may confidently expect the answers to them to become available within the next two to three years, as indeed they must if this system, which looks so promising on paper, is to hold its own with the other advanced reactor systems in practice.

References

[1] *Peaceful Uses of Atomic Energy*, 1955, Vol. 3, pp. 116 and 121, Papers P.936 and P.938, H. de Bruyn *et al.*
[2] *Peaceful Uses of Atomic Energy*, 1955, Vol. 3, p. 125, Paper P.494, F. T. Miles and Clarke Williams.
[3] U.K.A.E.A. Second Annual Report, 1956.
[4] *Nuclear Engineering*, July, 1956, p. 176.
[5] G. W. Greenwood and B. Sharpe, A.E.R.E. Report M/R.1829.
[6] G. W. Greenwood, *Acta Metallurgica*, 1956, Vol. 4, p. 243.
[7] *Peaceful Uses of Atomic Energy*, Vol. 9, p. 341, Paper P.118, J. R. Weeks *et al.*
[8] U.S.A.E.C. Semi-Annual Report, January, 1956, p. 65.
[9] *Nuclear Engineering*, August, 1956, p. 184.
[10] *Peaceful Uses of Atomic Energy*, Vol. 9, p. 321, Paper P.829, S. Siegal *et al.*
[11] R. J. Teitel, *Nucleonics*, 1956, **14**, p. 72.
[12] *Peaceful Uses of Atomic Energy*, Vol. 9, p. 604, Paper P.550, O. E. Dwyer, R. J. Teitel and R. H. Wiswall, Jr.
[13] W. H. L. Porter, A.E.R.E. Report M/R.1950.
[14] *Liquid Metals Handbook*, U.S.A.E.C.-Department of Navy, Second edition 1952, Na and Na-K Supplement, 1955.
[15] O. J. Elgert and C. J. Egan, U.S.A.E.C. Report MTA-12, January, 1953.
[16] R. Cygan, U.S.A.E.C. Report NAA-SR-1060, October, 1954.
[17] W. D. Wilkinson, U.S.A.E.C. Report ANL-4417, 1950.
[18] R. C. Reid, American Society of Mechanical Engineers, Technical Paper No. 51-S-13, 1951.
[19] V. W. Eldred, A.E.R.E. Report No. X/R.1806.
[20] J. R. Weeks, *Progress in Nuclear Energy*, 1956, Vol. I, Part IV, p. 378.
[21] *Reactor Handbook*, Vol. 3, *Materials*, 1955, U.S.A.E.C. Publication.

Erratum: The caption to Fig. 10 in Part 1 should read:
Group 2: Halogens. Groups 1 and 3: Metal with halides less and more stable than U Cl_3 respectively.

Probleme der Flüssig-Metall-Reaktoren

Lediglich zwei der flüssigen Metalle sind gegenwärtig von Interesse für die Verwendung als Brennstoff- und Schutzmedien für L.M.F.R. (flüssige-Metall-Reaktor-) Systeme, nämlich Natrium und Wismut. In Bezug auf die Natrium Technologie liegen bereits erhebliche Erkenntnisse vor; die Probleme, die in Wismut Systemen auftreten, sind weniger gut bekannt. Dieser Aufsatz ist deshalb der Betrachtung der Probleme, die bei Wismut auftreten, gewidmet.

Ein thermischer L.M.F.R. erfordert eine Mindest-Konzentration von reinem U 233 oder U 235 in Wismut von 600 p.p.m. (Teilen pro Million), und dies erfordert aus Gründen der Lösbarkeit eine Mindest Temperatur von 320°C. Die Kerngrösse würde bei einer solchen Konzentration ungefähr 5 Fuss × 5 Fuss sein mit gleichen Volumen von U.Bi und Graphit. Wenn die Wärmemenge für 500 MW erzeugt werden soll, so würde ein Flüssigkeitsstrom von 36.000 Gallonen je Minute (164.000 l./min.) erforderlich sein. Die Schutz-Schichten von einer Stärke von 3 oder 4 Fuss würden wahrscheinlich eine Suspension von Th_3Bi_5 in Wismut aufweisen.

In einer vorgeschlagenen Form eines solchen L.M.F.R. Systems wird eine Dispersion von U.Bi in einer Wismut-Legierung verwendet, jedoch werden die Probleme der Massenversetzung dabei ernstlich zu beachten sein. Dieser Gesichtspunkt wird in Einzelheiten diskutiert. Andere ernstliche Probleme betreffen die Durchdringung und Korrosion des Graphits, was auf ein Mindestmass zurückgeführt werden kann durch Imprägnierung und den Einsatz von Schutzmitteln.

Ferritische Stähle sind im Allgemeinen als Konstruktionsmaterial verwendbar, vorausgesetzt, dass die geeigneten Schutzmittel benutzt werden, wie z.B. Zirkon, welches, wie man glaubt, dann einen dünnen ZrN Film bildet. Andere verwendbare Materialien sind Niobium, Molybdän, Tantal, Wolfram und Beryllium, wobei man die Betriebstemperatur bis auf 800°C steigern kann.

Los Problemas de Reactores Alimentados con Metal Liquido

Solamente hay dos metales liquidos en la actualidad que son interesantes como combustible y como medios de "manteamiento" para los sistemas "L.M.F.R." (reactor de combustible de metal liquido), es decir, el sodio y el bismuto. Mientras que se conoce bastante sobre la technología del sodio, hay mucho menos entendimiento sobre los problemas relacionados con circuitos de bismuto. Por lo tanto, este articulo se dedica a una consideración de los problemas relacionados con el bismuto.

Un reactor térmico "L.M.F.R." necesita una concentración mínima de U 233 o U 235 puro en bismuto de 600 p.p.m., lo que, en cuanto a consideraciones de solubilidad implica una temperatura mínima de 320°C. El tamaño del núcleo para una concentración semejante sería de 5 pies por 5 pies (1.524 m. × 1.524 m.) aproximadamente conteniendo cantidades iguales de U.Bi y grafito. Si el calor fuera generado a 500 MW, el flujo de liquido que se necesitaría sería de 36.000 galones por minuto. Las "mantas" de un espesor de 3 o 4 pies (91.44 cm. o 121.92 cm.) probablemente contendrían una suspensión de Th_3Bi_5 en bismuto.

Una forma de "L.M.F.R." que se sugiere emplea una dispersión de U.Bi en aleación de bismuto, pero probablemente los problemas de transferencia en masa serían serios. Se discute este aspecto en forma algo detallada. Otros problemas serios se relacionan con la penetración y la corrosión del grafito, lo que puede reducirse al mínimo por impregnado y la introducción de inhibidores.

Los aceros ferríticos generalmente resultan convenientes como materiales de construcción, con tal de que se empleen los inhibidores apropiados, tales como el zirconio que se cree forma una delgada película de ZrN. Otros metales adecuados son el niobio, molíbdeno, tantalo, tungsteno y berilio, los que pueden extender la temperatura de funcionamiento hasta 800°C. Aun se conoce poco sobre la corrosión de ambos materiales de construcción de moderadores bajo el efecto de la irradiación.

Fabrication and Welding Techniques for At

Development work carried out by the John Thompson group on the design and fabrication of heat exchangers and pressure vessels. The welding of heavy steel plates is described, with survey and testing requirements. With stainless-steel fabrications and pipe-work, welding tolerances are extremely fine.

THE manufacture of plant for atomic energy projects entails new standards and techniques or, at least, the development and extension of existing methods, some of which have hitherto been used only on a comparatively minor scale.

In the construction of experimental or commercial reactor stations, a major part is being played by the manufacturer of the heat-exchange element. This section of the plant includes the reactor vessel and all that part concerned with the circulation of the heat-transfer medium, be it gas or liquid metal, from the vessel to suitable steam generating plant and the delivery of steam to the turbo-generator.

Manufacture of this substantial section of the nuclear power station is being carried out by adapting and extending the facilities which have been built up over the years for the production of boiler plant for thermal power stations and to some extent for the manufacture of pressure vessels and process plant for the chemical industry. Developments which have taken place within the research, design and manufacturing department of the John Thompson Group are typical, relating as they do both to the fast-breeder reactor station at Dounreay and to the graphite-moderated, gas-cooled reactor of the type required for Britain's first commercial nuclear power stations.

Present designs of these two types of reactor station call for considerably different use of materials. In the liquid-metal-cooled fast-breeder reactor extensive use is made of stainless steel. The gas-cooled reactor calls for adapted techniques in the fabrication of mild steels.

Heat-exchanger Design

In a gas-cooled reactor station the heat exchanger is similar in many respects to a water-tube boiler. Any differences, however, are mainly in the type of heating surface employed and the arrangement and housing of this surface.

The exchangers are required to deal with clean gas at a pressure of 10 atm. and a temperature in the region of 700°F. They must transfer the heat from this gas to produce steam, whilst maintaining a specified gas-outlet temperature and gas pressure drop.

The relatively low temperature of the gas necessitates some form of extended heating surface to keep the exchanger design compact, and the fact that the gas is clean allows the use of this type of surface with little likelihood of fouling. The pressure of the gas requires that the surface be contained in a pressure vessel, and the best form is a cylinder with gas flow axially, the design being such as to provide a reasonable gas flow area consistent with the minimum gas pressure drop and circulating blower power on the one hand, and with economy in size and material on the other.

Very little reliable information exists on the performance of extended surfaces. With the multitude of possible surfaces, a complete experimental analysis would be prohibitive. Fortunately, there are enough data available to enable approximate design studies to be made. These, taken in consideration with other features, such as the price and availability of various types of surface, reduce the experimental field to be covered.

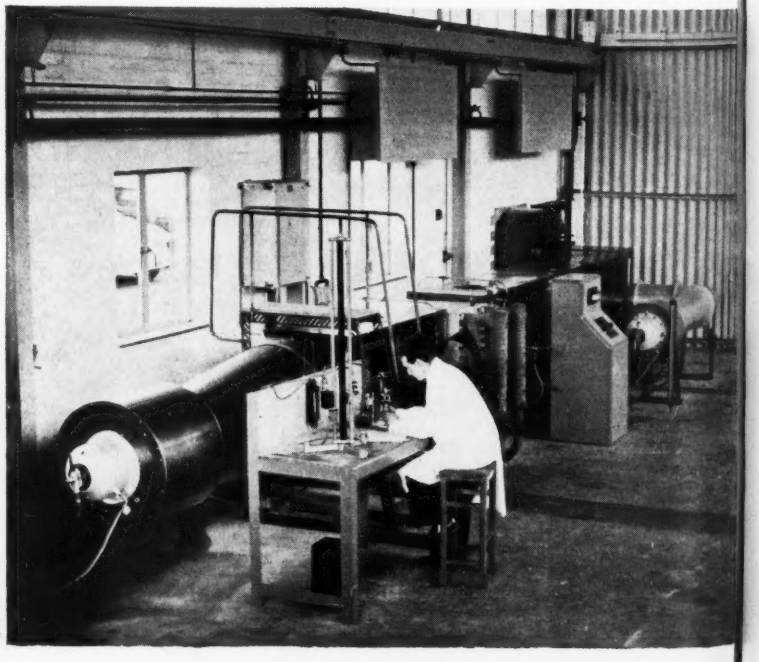


Fig. 1 (right). A heat-transfer test rig used in the design of heat exchangers at John Thompson's research centre.

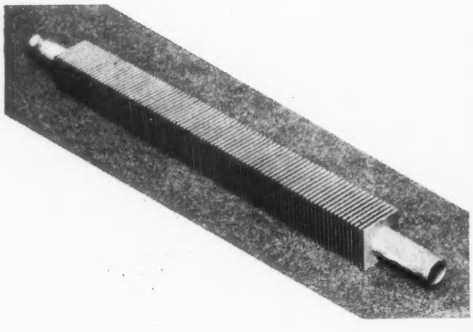


Fig. 2. Finned tube, with square fin section, providing a large heating surface and permitting close packing for gas-to-water heat exchange.

Atomic Energy Plant

Even with this narrowed field, the experimental work is still lengthy; further, it is not desirable to carry out tests on model-size equipment with its associated indeterminate scale effects. Consequently, a rig has to be designed to test a bank of full-size tubes, the bank itself also being of reasonable dimensions. Another essential is that the tests must be carried out on the surface as it will be installed in the actual exchangers, and that the test surface be manufactured from the actual full-scale constructional material and by the same process. Final tests must also be carried out on the tube configuration of the completed exchanger design.

Fig. 1 shows a heat-transfer test rig in operation at John Thompson's research centre, and Fig. 2 shows a section of finned steel tubing which has been subjected to tests in this rig.

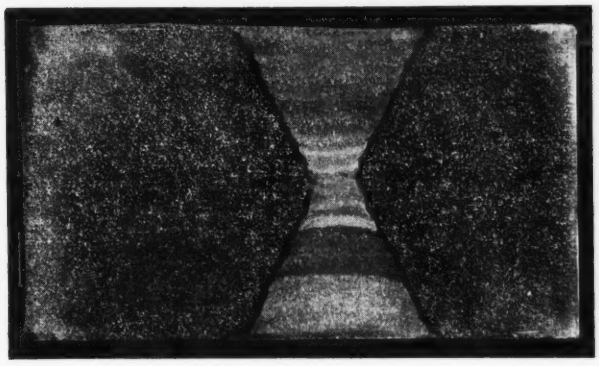
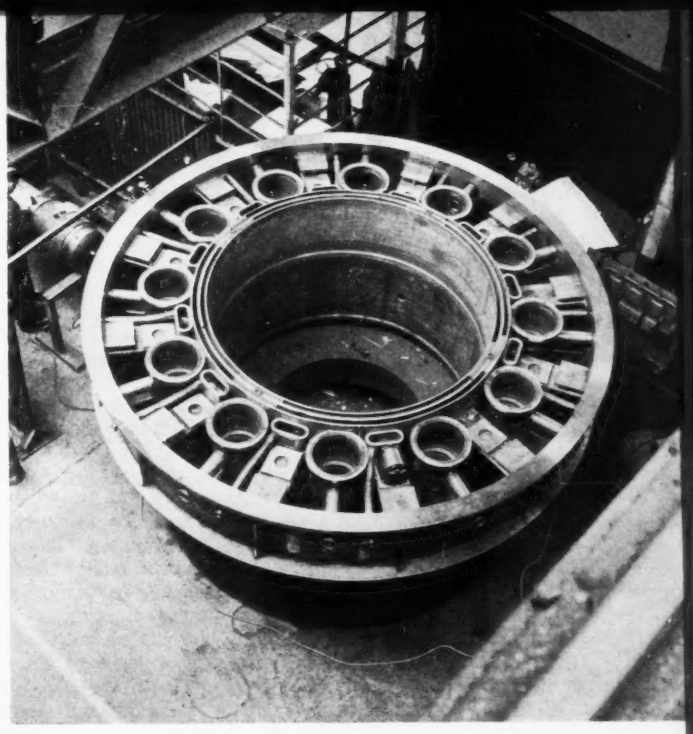


Fig. 3. Double-V vertical butt-weld in 3-in. plate, welded with low-hydrogen-type electrodes.



A section of the complex stainless-steel vessel, which will contain the Dounreay fast-breeder reactor, at the Wolverhampton works of John Thompson Ltd.

Pressure Vessels

The pressure vessel itself may be of the order of 18 ft. diameter by 70 ft. high and there may be as many as eight per reactor. Although the design is reasonably simple, the size presents some constructional problems, including part-shop and part-site fabrication to Class 1 welding standards. For site welding, well-established criteria may be applied to the selection of the steel. It must have satisfactory physical properties with regard to creep and tensile strength as well as adequate notch ductility and weldability. In addition, all plate must be physically sound and free from laminations: ultrasonic testing is resorted to before fabrication.

In deciding on a suitable steel, the choice is to a great extent limited to what material is available from the steel mills. In general, the vessels are made from plates from 3 to 4 in. in thickness and of a size and weight up to the maximum that British mills can roll.

The choice of steel is governed by the requirements of the service conditions and is one of long-term resistance to the effects of stress, temperature and the environment. In the particular case of reactor pressure shells, the requirements of the steel for creep resistance is that it must possess adequate ductility to accommodate slow rates of strain and will withstand the combined constructional and working stresses at operating temperatures for the lifetime of the plant.

At low temperatures, aluminium-killed mild steels have better notch ductility and transitional temperature than silicon-killed mild steel, but unfortunately they have a poorer creep resistance and for temperatures ranging from 375°C to 450°C there is not a satisfactory mild steel which will give resistance to creep, and alloying becomes necessary. For temperatures up to 375°C a satisfactory standard of creep with adequate freedom from notch brittleness is possible.

Adequate notch ductility to meet site fabrication conditions is ensured by close control of the carbon and manganese contents; the carbon is limited to 0.16% and the manganese to 1.0-1.45%, whilst the steel should be used in the normalized condition.

Little is known as yet about the effects of irradiation on the physical properties of steel, but one obvious effect is that metal used in the reactor itself will become radioactive due to the presence of trace elements, such as cobalt; hence it is most desirable that such elements are kept to an absolute minimum.

Heavy Plate Welding

John Thompson (Wolverhampton) Ltd. have had considerable experience in the manufacture of large, heavy pressure vessels over a long period of time, and the welding of plates of the thickness required for large reactor vessels is not new to them. However, because much of the fabrication has to be carried out under site conditions, special techniques have had to be developed to cover the all-positional welding called for.

It has been found that both psychologically and physiologically site operation can have marked effects upon the skill of the welder. Different working conditions, climate, living accommodation and absence from home and family all have their effects on the operator. Precautions must therefore be taken to see that welders are tested periodically under site conditions.

In the John Thompson Group research laboratory a series of experiments has been carried out to determine the most satisfactory weld preparation for site welding of 3-in. to 4-in. thick plates.

The joints considered were vertical welds, horizontal welds in vertical plane and radial and circumferential welds in vessel ends.

From the information obtained recommendations can be made of the type of preparation, type of electrode and welding procedure and equipment required.

For the vertical welds the double "V" preparation using an included angle of 50° has been found satisfactory. The root gap is important, as a narrow base to the "V" makes back chipping difficult; hence the gap should be sufficient to give good access to the electrode with economy of weld metal, but should also be wide enough to allow the use of a pneumatic chipping tool. A typical section of weld produced under these conditions is shown in Fig. 3.

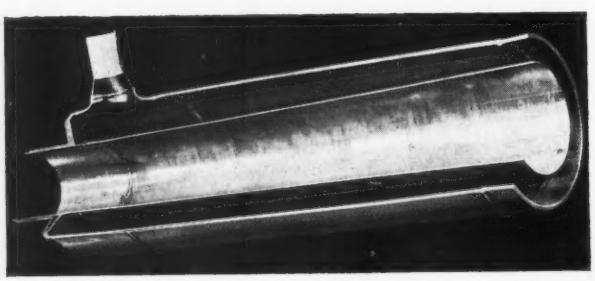
Horizontal welds in the vertical plane are also double "V" welded, but in this case the "V" is lopsided, being 10° on the bottom face and 35° on the top face, to give a double included angle of 45°. Sufficient root gap must be maintained to allow of back chipping.

Testing of Welds

An essential feature of Class 1 welding is the non-destructive examination of the joints by radiography. The site examination of plates 3 in. to 4 in. thick is made difficult by the unsuitability of available equipment, the choice of X-ray units for this class of work being very limited. X-ray sets that will penetrate metal of 4 in. thickness are very large, being rated at 1,000 or 2,000 kV, and are not portable. There is also the problem of shielding such sets on *in situ* jobs.

Consideration has been given to the possibilities of using large gamma sources instead of X-rays and while in some applications, such as pipe joints, they have advantages, X-rays are generally preferable in that they are much quicker.

The radiographic procedure for welds 4 in. thick must be the best possible to be of value, and this means that the use of lead screen techniques is imperative. Unfortunately, this results in either increased exposure times or the need for higher voltage from the X-ray unit. To meet the requirements for X-ray sets that are reasonably portable and with sufficient output to give exposures in an economical time, John Thompson Ltd. are having special 400-kV constant-potential X-ray units of revolutionary design built for these projects. They will satisfactorily penetrate 4 in. of steel in economical exposure times.



Section of stainless-steel heat exchanger pipe-work, showing extrusions, branches and butt-welds forming inner and outer liquid-metal circuits.

Whilst radiographic examination is a specified requirement for the pressure vessels, other methods of non-destructive testing have not been overlooked. Magnetic and ultrasonic examination will be used for information purposes, particularly on those joints that cannot be satisfactorily radiographed.

It might be appropriate here to describe the procedure at Calder Hall.

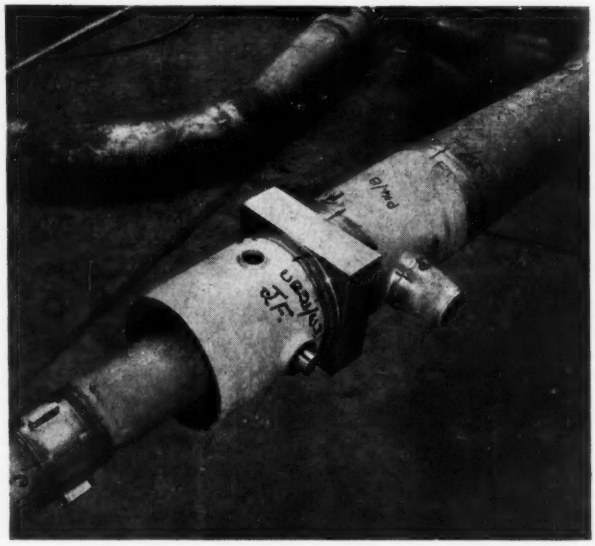
The survey of the pressure plant, that is, reactor vessels, heat exchangers and gas ducting with included valves and expansion bellows during construction and testing in the manufacturers' shops and on site, was carried out by Lloyd's Register of Shipping, Land Division.

Certain basic inspection requirements were stipulated for all parts of the gas circuit. Briefly, these can be listed as careful choice of materials followed by tests and examination in the steelworks and at all subsequent stages of manufacture, the rigorous testing of all welding procedures and welders to carefully drawn up specifications, 100% X-ray of all butt-welded seams using approved techniques, the magnetic crack detection of nozzle and fillet welds, careful dimensional checks at all stages—some intermediate—and complete final testing.

On the reactor vessel itself, in addition to normal tests at the steelworks, each plate of the specially chosen notch-tough steel was ultrasonically tested for laminations and its toughness proved by Charpy "V" notch tests; no minus tolerance was permitted on thickness. Thick plates in which large nozzles were welded in the shops were there tested and stress-relieved before being sent to the site. On site, where all the main fabrication had to be carried out because of the vessels' size, the Society's surveyors tested each welder before he was allowed to start work, had intermediate and final test plates made, supervised construction, examined X-ray films and decided on any repairs necessary, checked dimensions, carried out crack detection, and witnessed stress-relieving of the complete vessel and finally the pressure tests.

Pressure testing had to be by air, with its consequent potential hazards. To minimize these, it was decided that, in addition to the careful survey throughout the design and construction stages, strain gauges would be used to give the general stress level and also check those areas where locally high stresses might be expected to occur. Brittle lacquer was used as a coarse check. The Society's Research Department undertook the strain gauging, using equipment and knowledge built up by them on several previous large vessel investigations. About 350 gauges were used on the first test where, after a preliminary run, zero-50 p.s.i.-zero to check drift, pressure was applied in increments to 135 p.s.i. At each pressure stage a full set of readings was taken from the strain gauges and any which showed that stresses were significant were checked more frequently. Brittle lacquer was examined at each stage after pressure had been dropped 10 p.s.i. from that at which strain-gauge readings had been taken and stresses calculated; dimensional changes were recorded concurrently. The initial cold-air test was followed by a vacuum test; when the vessels were loaded with graphite the cold-air test was repeated to 115 p.s.i., this being followed by a hot test to the same pressure with air at a temperature of 284°F

Test pieces taken from the welded test plates were required to pass the Society's rules for Class 1 welded pressure vessels.



Typical transition piece of the Dounreay pipe-work showing the spacing spider (extreme left) butt-welded on to the inner circuit.

Argonarc welding a section of stainless-steel liquid-metal pipe. Note the bellows expansion joint.

Stainless-steel Fabrication

With some reactor designs, such as that at Dounreay, the necessity for absolutely leak-free systems has meant building large containers in which all access is limited to one end only, and the consequent congestion of facilities has resulted in intricate welding fabrication. Further, the use of highly-corrosive liquids has demanded the widespread use of stainless steel. For instance, with the exception of brackets and stiffeners, the entire reactor vessel is built up, with butt welds to Class 1 requirements, from stainless steel plates up to 4¼ in. thick, welded together, levelled, and then machined away to half the original weight to form suitable preparations for further welding. Careful stress-relieving has to be done at intermediate stages of the operations, especially machining.

The tolerances called for with the welding of stainless steel are quite outside general practice, and manufacturers are asked to maintain such limits as less than 0.1% ovality, 0.03% alignment and almost perfect concentricity, where several diameters are involved. It can be appreciated that on a complex stainless-steel unit, where the components range from 12 S.W.G. to 4½ in. thick, these factors present major problems in construction.

The greatest problem is to avoid distortion from welding, machining and heat treatment, which, unfortunately, cannot be tackled in the normal way, as the unit may be so complex that access alone may completely dominate procedure. This factor is so vital to some operations that full-size mock-ups have been made and special tools devised before it has been possible to establish a sequence of operations.

Manipulation also presents a difficult problem because, although the large structures are fairly rigid when complete with stays and stiffeners, during fabrication they have to be often moved in a weaker state and much time is lost in precautionary measures and the making of special jigs and fixtures.

A wide range of welding methods is used, employing anything from miniature argon torches to the heaviest "straight" electrodes, and some idea of the amount of chipping and grinding necessary can be gathered from the fact that nearly 3,000 X-ray or gamma-ray negatives are taken on a large unit, and a large percentage of the weld does not permit the use of standard heavy tools.

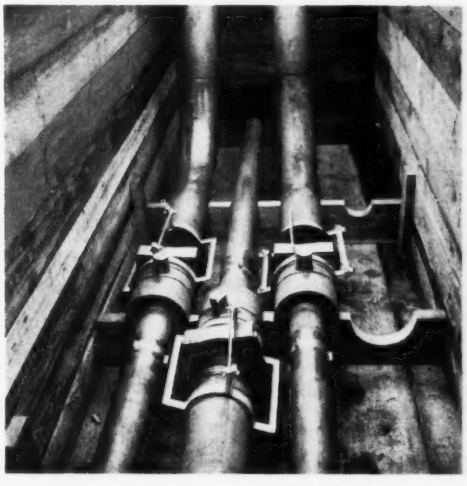
During construction a rigid programme of stress-relieving, pickling in stages and intermediate testing is adhered to, while the final pressure and mechanical testing lasts for several weeks.

Stainless-steel Tubes

The use of liquid-metal circuits in the fast-breeder reactor has also necessitated special fabrication techniques in stainless-steel tubing. Quality control of the highest order is maintained throughout manufacture, commencing at the steel maker's works. Steel is inspected at the billet stage and, after piercing and hot-drawing into hollows, further rigid inspection follows. Each completed hollow is subjected to interscope inspection and all faulty marks are ground out. The hollows are then cold-drawn to size, pickled and again inspected. After cold-drawing, the tubes are hydraulically tested and finally inspected under water while filled with air to a pressure of 100 p.s.i.

At John Thompson's works the tubes are cold bent on a mandrel-type machine, using a special lubricant and dies to avoid steel pick-up during the operation. They are then degreased and the bends subjected to heat treatment (approximately 1,050°F) to remove all bending stresses. Tubes are then pickled in nitric and hydrofluoric acid to remove all scale.

To allow of radiographic examination all welds are, wherever possible, of the butt-weld type. Tubes of 14 S.W.G. thickness and above are machined on the ends to give the correct welding profile of $\frac{1}{16}$-in. maximum root face and $\frac{1}{16}$-in. lip.



Finished stainless-steel transition pieces, rubber-capped and crated for dispatch.

The use of butt-welding, in turn, requires that all branches and drain pockets are made by extruding a nipple on to the pipe and butt-welding on to the nipple.

In the extruding process, an oval-shaped hole is first cut in the pipe, care being taken to ensure that the edges are machined smooth. Then the pipe is locally heat treated round the hole and a plug of special steel is pulled or pushed through. The extrusion is then heat treated again and pickled, and finally examined for faults.

It is imperative that in the welded liquid-metal-circuit pipework the internal bead shall be as smooth as possible. This is achieved by control of the argon gas employed in the argon-arc welding process. By experience, a degree of control has been achieved which produces a very high quality result.

In the welding process, all separate items are accurately

fitted together with close butt-joints to ensure the best possible welding set-up. The inside of the tube is sealed off local to the weld with soft rubber bungs, and the space between the bungs is filled with argon in order to reduce internal oxidization and scaling to a minimum. The base run of the weld is made with an argon torch, fusing the walls of the tube without the use of filler wire. Subsequent runs are carried out with the addition of filler wire of high-grade stainless steel.

Completed units are X-ray examined by the double-wall technique. They are also leak detected by filling with nitrous oxide under pressure, using externally-placed detection apparatus.

The final assembly is then hydraulically tested and degreased by pumping a degreasing solution through the circuit. It is then washed out with clean water and given an internal light pickle of nitric and hydrofluoric acids. This is followed by drying and treating with heated, filtered air to remove all traces of water and dust. Finally, the open ends are capped with rubber caps, securely fixed into position by mechanical means.

Aluminium Pipe-work

Many thousands of feet of aluminium pipe-work systems have been employed in chemical-treatment plants in the atomic energy field. Fabrication is carried out to very high standards, particularly in regard to the essential freedom from leakage and also with special precautions for cleanliness, the methods being generally as for stainless-steel systems.

In preparation for welding, which is carried out by the argon-arc process, pipes of thickness greater than $\frac{3}{16}$ in. are machined to form a lip-weld contour. For pipes of lesser thickness, a close butt-weld is used and the walls of the pipe are fused for a bead-run weld. Where possible, welding is facilitated by the use of a removable internal backing ring made of stainless steel with a depression in the centre to form the contour of the internal bead. This ring is held rigidly in position by mounting it on compressed-air plungers. Where such a backing ring cannot be used, greater skill is required of the operator.

Extrusions are produced by means similar to those in stainless-steel tubes, except that the oval hole is thickened up at the extremities to achieve the required contour.

Normally, aluminium systems have to be vacuum tested as complete units. First the pipe-work is degreased by filling with a suitable agent, washed out with soft clean water and pickled. The unit is again washed out and heated by hot clean water so that the heat imparted aids drying out afterwards. After vacuum testing, the units are sealed with rubber caps ready for dispatch.

An example of aluminium fabrication for chemical treatment plant, with extensions and butt-welded branches.

Les Techniques de Fabrication et de Soudure pour les Récipients et la Tuyauterie

Les échangeurs de chaleur pour les réacteurs refroidis au gaz sont analogues à beaucoup d'égards à une chaudière aquatubulaire et les problèmes de la conception se portent principalement vers le type de surface de chauffe et ses disposition et logement. On y donne des détails des études et des travaux de développement dans ce domaine entrepris par le group John Thompson.

L'installation de pression pour ce type de réacteur est d'habitude très grande et requiert une fabrication en partie en usine et en partie sur les lieux. Le choix de l'acier est déterminé par des considérations de dessin ainsi qu'une ductilité à l'échancrure de filière et une capabilité de soudure suffisantes. Les normes requises pour la vue d'ensemble de ce genre de récipient sont particulièrement sévères, toutes les soudures de Classe 1 étant soumises à un examen radiographique, des contrôles soignés étant effectués à tous les stades. En outre, les récipients soivent être soumis à des essais pour le relâchement de la tension, et pour la pression.

Dans le cas de la fabrication en acier inoxydable toutes les jointures sont soudées bout à bout, les tolérances requises étant à fait en dehors de la pratique normale. Les fabricants doivent tenir des limites de moins de 0,1% de circularité, de 0,03% d'alignement et une concentricité presque parfaite sur des éléments constitutifs allant du numéro 12 de jauge S.W.G. à une épaisseur de 114 mm.

Zusammenbau von Behältern und Rohrsystemen und die dabei zur Anwendung kommende Schweisstechnik

Wärme-Austauscher für gasgekühlte Reaktoren sind in mancher Hinsicht ähnlich einem Wasserrohr-Dampfkessel, und Konstruktionsfragen drehen sich im wesentlichen um die Art der Heizfläche und ihre Anordnung und Einbau. Es werden detaillierte Angaben über Forschungs- unl Entwicklungsarbeiten auf diesem Gebiet gebracht, die von der John Thompson-Gruppe ausgeführt worden sind.

Die Hochdruck Anlage für diesen Typ con Reaktoren ist gewöhnlich recht gross und erfordert Herstellung teilweise in der Fabrik und teilweise auf der Baustelle. Die Wahl des Stahles ist abhängig sowohl von der Art der Konstruktion als auch von der Kerbzähigkeit und Schweissbarkeit. Die Ueberwachungs Vorschriften sind für diese Art von Behältern sehr scharf; all Schweissnähte der Klasse 1 müssen radiographisch untersucht werden, und in allen Arbeitsgängen sind sorgfältige Prüfungen vorgesehen. Ausserdem müssen die Behälter Beanspruchungs-Proben für Entlastung und Druck unterzogen werden.

Bei der Verwendung von rostfreiem Stahl müssen alle Verbindungen stumpf geschweisst werden, und die Toleranzen, die einzuhalten sind, liegen ganz ausserhalb des im allgemeinen Ueblichen. Fabrikanten müssen innerhalb einer Toleranz von 0,1% in Hinsicht auf Kreisrundheit und von 0,03% in Hinsicht auf Ausrichtung bleiben, und es wird fast vollkommene Konzentrizität verlangt bei Teilen von einer Stärke von 12 S.W.G. (2,64 mm) ab bis zu 4½ Zoll.

Técnicas de fabricación y Soldadura de recipientes y tuberías

Los cambiadores de calor para reactores enfriados a gas son similares en muchos respectos a una caldera de tubos de agua y los problemas de diseño se relacionan mayormente con el tipo de superficie de enfriamiento y su disposición y alojamiento. Se ofrecen los detalles de la labor de investigación y evolución llevada a cabo por el grupo John Thompson.

El equipo de presión para este tipo de reactor es generalmente muy grande y exige fabricación en parte en el taller y en parte en sitio. La selección de acero se determina por consideraciones de diseño así como de adecuada ductilidad de muesca y posibilidad de soldadura. Las exigencias para reconocimiento de este tipo de recipiente son muy estrictas, siendo que toda soldadura de la Clase 1 se somete a examen radiográfico, haciéndose cuidadosas verificaciones en todas las etapas. Además, los recipientes tienen que ser sometidos a ensayos para alivio de tensiones y ensayas de presión.

Con la fabricación en acero inoxidable todas las juntas son soldadas a tope, siendo las tolerancias exigidas completamente fuera de la práctica general. Los fabricantes tienen que mantener límites de menos de 0,1% de circularidad. 0,03% de alineación y casi perfecta concentricidad sobre componentes que varian desde 12 S.W.G. hasta 4½ pulgadas (11,43 cm.) de espesor.

Calder Hall

The B.N.E.C. Symposium Papers

SESSION 1—THURSDAY, NOVEMBER 22

INTRODUCTION AND GENERAL DESIGN

The Place of the Calder-Hall Type of Reactor in Nuclear Power Generation *by Sir Christopher Hinton, M.A., M.I.C.E., M.I.Mech.E., M.I.Chem.E., F.R.S. (managing director, Industrial Group, U.K.A.E.A., Risley)*

Introducing the symposium, Sir Christopher makes no apology for repeating many facts on the history of nuclear power developments in the United Kingdom and goes on to quote Sir Charles Inglis as saying ". . . there are occasions when it seems to me that the repetition of the obvious is of greater importance than the elucidation of the obscure".

When the British Atomic Energy Organization was set up in 1946, it was intended that the graphite-moderated, water-cooled piles of the original Hanford type should be built. These, however, are not inherently safe and, due to the relatively high concentration of population in the British Isles, could not form the basis for an atomic energy programme. Safety considerations therefore dictated that another system should be adopted. Whilst it was known that the Americans had not used gas cooling because of the difficulty of obtaining sufficiently large blowers, the work of Gott and Ginns proved that extended surfaces on the fuel cans would make gas cooling possible. Diamond and Hodge showed that the heat-transfer work could be interpreted so as to include a coolant working at atmospheric pressure and that, in fact, a scaled-up version of BEPO was practicable. The design and construction of the Windscale reactors was completed in 1950. In the meantime, a preliminary design study of a power reactor with a pressurized-gas coolant indicated that an overall efficiency of 19.8% could be achieved. Discussions then took place over the question of deploying further effort on the gas-cooled system rather than concentrating it on the fast reactor. Further study was undertaken by Goodlet and Moore under Tongue, and a preliminary scheme for a nuclear power plant was worked out which, when optimized for the generation of electricity, appeared to offer an efficiency of about 25%. At the time when these studies were complete, a demand was received for additional plutonium for defence purposes and the modifications to the initial design were undertaken by Kay, Geoghegan and Poulter, who calculated that the gas-cooled reactor optimized for plutonium could produce electricity at 1d. per unit. Their report was used for a basis of inter-departmental study and, with some developments and modifications, formed the basis of the White Paper which was published in February, 1955.

An analysis of previous experience in the construction of steam prime movers and land-based oil engines suggests a logarithmic reduction in capital cost with a possible "half cost" of 25 years.

The 1951-53 Harwell Design Study *by R. V. Moore, G.C., B.Sc. (Eng.), M.I.Mech.E., M.I.E.E., and B. L. Goodlet, O.B.E., M.A., M.I.C.E., M.I.Mech.E., M.I.E.E. (assistant director (civil reactors), U.K.A.E.A., Risley and director and chief engineer, Brush Electrical Engineering Ltd.)*

The plant described in this paper is the original Harwell design and the reasoning and conclusions are of 1953. No attempt has been made to bring the paper up to date by incorporating more recent work.

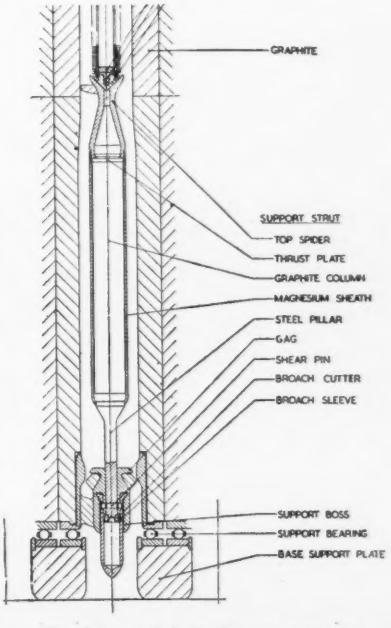
The authors were presented with the problem of designing a natural-uranium power reactor towards the end of 1950. On a first appraisal, taking BEPO as background, 30 ft. appeared to be a probable diameter of the reactor core. Previous experience for the manufacture of drum boilers indicated that, with a diameter of 30 ft. or so, an operational pressure of about 7 atmospheres was feasible. Initially, the Windscale-type horizontal-axis reactor inside a pressure vessel was visualized, but this was finally rejected because the support and restraint of the heavy graphite core from the curved surface of the pressure vessel proved an intractable problem. Vertical-axis design was indicated.

The main features of the design selected included a graphite core built of individual machined blocks to a diameter of 36 ft. and a height of 27 ft. supported from a steel structure on a large number of rollers. Each core channel was to contain five uranium fuel rods about 4 ft. long, supported by collapsible crowfeet stands resting on circumferential ledges in vertical channels. The choice of fuel-element canning material lay between aluminium and magnesium and, after careful metallurgical investigation, the magnesium alloy was decided upon. At the instigation of R. A. U. Huddle, a number of magnesium alloys containing beryllium were made up by Magnesium Elektron Ltd. One of these proved to be compatible with wet air at 600°C. Experimental work was undertaken to determine the feasibility of using CO_2 as coolant as the only reasonable alternative to helium. Mass transfer experiments were also undertaken which indicated that the initial rate of weight loss of graphite would lie between 0.1% and 0.2% average per year. Corrosion of the pressure vessel steel by CO_2 was found to be surprisingly high, amounting, at 350°C, to a penetration of 0.003 in. per year. Since this was the maximum temperature envisaged, and a corrosion allowance of $\frac{1}{16}$ in. had been provided, no anxiety regarding vessel life was felt, but measures were taken for preventing scale and for filtering a small bleed from the gas stream.

It was clear by mid-1952 that a centre-channel heat output of at least 160 kW was possible, and that for an unflattened reactor with the ratio of average-to-maximum channel output of 0.53 the attainable heat rate was at least 144 MW.

The paper goes on to discuss the conclusions reached on the choice of steam cycle and other problems of general design governing the choice of control-mechanism entry into the pressure vessel and the methods of support of the pressure vessel.

It was concluded that there was little hope of obtaining steel for the pressure vessel's construction with an average cobalt content of less than 0.005%.



Graphite and fuel element support.

The Design and Construction of the Plant *by R. V. Moore, G.C., B.Sc. (Eng.), M.I.Mech.E., M.I.E.E. (assistant director, civil reactors, U.K.A.E.A., Risley)*

This paper discussed first the reassessment of the original Pippa design—which laid emphasis on the production of electricity—when it was decided that the primary purpose of the plant should be the production of plutonium with electric power as a by-product. The main parameters and performance of all the items of plant at Calder Hall were then discussed, the paper thus serving as a general introduction to the more detailed information in subsequent papers.

In addition, it reviewed briefly the structural design and civil engineering work, as well as the supply, machining and placing of the graphite.

In conclusion, the author pointed out that the completion of the plant to a time scale and to a cost estimated at the outset showed that, in spite of new features and techniques, this type of plant could be efficiently designed and built. Further, being constructed of materials in common use, and with natural uranium as fuel, plants of this type did not require the prior production of special and very expensive materials such as enriched uranium and heavy water.

SESSION 2—THURSDAY, NOVEMBER 22

TECHNICAL RESEARCH PROBLEMS

Heat-transfer Experiments on the Fuel Elements *by P. Fortescue, B.Sc., Ph.D., Wh.Sc., and W. B. Hall, B.Sc. (Eng.), A.M.I.Mech.E. (deputy chief scientist of reactor division, Harwell, and development branch, Sellafield)*

This paper describes the development of the Calder Hall fuel-element units, showing their evolution from the longitudinally-finned type of element utilized at Windscale. There was, of course, a fundamental difference in requirements, since the Windscale working conditions were very different, there being no necessity for high outlet temperatures, since no use is made of the heat. Early experiments on longitudinal-finned cans showed that the coolant tended to stratification in the inter-fin spaces and a consequent high-temperature gradient in a radial direction. Experiments with turbulence-producing devices to promote mixing of the coolant in the inter-fin spaces led to trials of the cross-finned type. It was thought that the fin surfaces would not be swept by the coolant and the turbulence would cause excessive pressure drop. It was later discovered that there is a systematic flow between the fins in the form of two vortices "geared" together as it were, and that the efficiency of this type of fin was surprisingly high.

Experimental work was mostly carried on with atmospheric air, principally owing to the difficulty of measuring temperatures in pressurized apparatus. Electrical heating was mainly used to simulate the heat release from the element.

An interesting feature of the work is an investigation into the actual velocities at different positions in the inter-fin space by a large- scale model, in which air is drawn through a rectangular section channel with transverse fins on the lower wall, the air velocity at various positions being measured by a hot-wire anemometer. This, of course, only measures velocity and not direction of flow, and a more complete picture of the flow is being investigated by a "yawmeter". Further work, which is still proceeding, is devoted to measuring the distribution of heat release in various parts of the fins by an insulating fin with a series of heater strips, so that the input to individual strips can be readily measured. It is also hoped to obtain further data on the effect of fin-tip profile on heat transfer and drag. Information on the flow pattern has also been obtained from water channel tests, using a can model immersed up to its centre line and aluminium dust to delineate the flow pattern.

Experimental Physics *by P. W. Mummery, M.A., F.Inst.P. (deputy group leader of the thermal reactor group, reactor division, A.E.R.E., Harwell)*

The critical conditions for a reactor can be expressed by the continuity equation: neutron yield = neutron absorption + neutron leakage and the solution of this equation requires the basic nuclear data to be available. An uncertainty of 2% in the neutron yield per neutron absorbed in U 235 will lead to an uncertainty of a factor two in the critical size of a reactor of the Calder-Hall type. Initially, a selection had to be made of the fundamental nuclear data that were available which, combined with a simple mathematical model of the behaviour of the neutrons in the system, could yield predictions which could be correlated with results of integral experiments.

Of considerable importance in the evaluation of criticality conditions is the density and purity of graphite. An increase in the purity can lead to most marked reductions in critical size, whilst an increase in the graphite density can result in an improvement in the neutron economy and also an increase in the amount of uranium contained in the unit body of the reactor.

The presence of coolant channels increases the neutron leakage from a given sized reactor more than might be expected from a simple consideration of graphite-density reduction, due to the migration length being determined by the root mean square distance which the neutrons travel. The migration length of neutrons in the reactor is asymmetric.

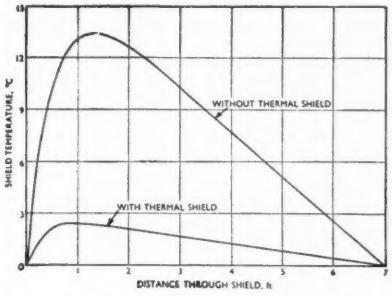
From the physics viewpoint, there is an optimum fuel-element size for a given fuel shape due to the competition of the fast fission factor and resonance escape probabilities on the one hand, and the thermal utilization factor on the other. The availability of enriched material, however, allows considerable flexibility in design, but an economic assessment of such use is complex.

The paper discusses the basis of the experimental and theoretical work and describes the order in which fundamental data were assembled. Following this, exponential experiments were carried out on assemblies with lattice pitches varying from 7 in. to 9⅝ in. each with a coolant-channel diameter from 1½ in. to 3¼ in. Fine structure measurements were made using the thermal column of GLEEP with a neutron flux of 10^7 n/cm²-sec. Other experiments involved the measurement of diffusion lengths in graphite, the effect of coolant channels on characteristic areas and an examination of the poisoning effects of fission products and the build-up of fissionable plutonium. These last experiments have indicated that a burn-up of 3,000 MW-days per tonne is practicable with the Calder-Hall type of reactor.

Shield Design *by C. C. Horton, B.Sc., and W. Bonsall, B.Sc. (reactor division, A.E.R.E., Harwell, and technical section of the engineering branch, U.K.A.E.A., Risley)*

The reactor system formed an exceedingly complex source of penetrating radiations and in order to obtain a solution in a reasonably short time many approximations were used to simplify the problems. The reactor was regarded as a flat slab rather than a cylinder, as the radius is much larger than the shield thickness, and the gas ducts as simple line sources. Where necessary, deliberately safe approximations were made, such as that of assuming that the energy release from neutron capture in carbon was all at an energy of 5 MeV.

The shield design can be divided into three main categories: radiation through the main shield, radiation from activation of the coolant and heat generation in the



Temperature rise in shield.

shield which was reduced by the interposition of a 6-in. iron thermal shield, incidentally reducing the concrete thickness by 20 in.

Datum on concrete as a neutron shield was limited, but results were extrapolated from those obtained on BEPO. Gamma rays arise from fission in the fuel and n, γ capture in the core material, reflector, pressure vessel, thermal shield and the shield itself. The flux arising from these sources was calculated by geometric formulæ. The distribution of the neutron flux in the reflector is almost linear with thickness, whereas it can be considered uniform in the core region. Direct gamma radiation, however, from the core represents only 5% of the total emergent current. Relatively recent calculations of build-up factors will allow an easier approach to calculations of shielding efficiency in the future.

The total flux on the exterior of the shield is calculated to be 5.5 mr/h, made up of: n, γ capture in the graphite 0.7%, pressure vessel 23.5%, thermal shield and concrete 37.9% each.

Little information was available on radiation streaming through the ducts and the assumption made, that radiation at the two right-angled bends was scattered isotropically, was pessimistic.

In calculating the activation of the coolant, radiation from A 41, N 16 and O 19 must be considered. The table gives calculations of dose rates at significant points at a distance of 2 ft. from the radiating surface. The heat exchangers were

RADIATION DOSES

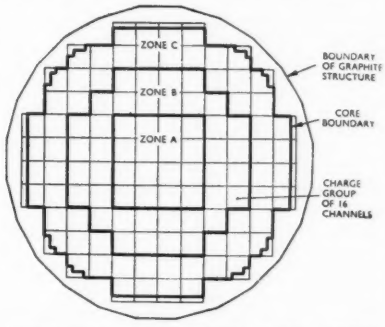
Position in circuit (2 ft. from surface)	Dose-rate, mr/h, due to ^{41}A	^{16}N	^{19}O	Total dose-rate mr/h
Reactor exit pipes ...	19	48	2	69
Top of heat exchangers ...	2	8	0.2	10
Bottom of heat exchangers	3	6	0.2	9
Reactor inlet pipes ...	26	23	2	51

treated as homogeneous cylinders of a certain average density. As no dose-rate exceeded by a factor of 10 the maximum permissible level, it was concluded that additional shielding was unnecessary and limited access would suffice.

Calculations of heat generation in the shield led to results which give as a rough rule of thumb a maximum temperature rise in the thick concrete shield of about 0.5°C per B.T.U. per sq. ft.-h heat input.

Basic Design of Reactor *by G. Packman, B.A., Grad.I.Mech.E., and B. Cutts, B.Eng. (thermal reactor design office and research and development branch, U.K.A.E.A., Risley)*

From the design study, four important factors influencing basic design emerged. The first of these was that the cross-section of magnesium was smaller than was at first believed; the second that the absorption cross-section of the better-quality graphite was nearly 20% below that used in the Windscale reactors. The decision was to use CO_2 as a coolant and the availability of enriched material would allow greater flexibility in the design, so that errors on the wrong side could be made good by enriched material. A deficiency of ½% in reactivity could mean a reduction of heat output of about 40%. By the middle of 1955 the results of a large number of exponential experiments were available which increased the estimated reactivity of the Calder-type lattice by about 0.7%, but there was still a possible uncertainty of ±0.5%.



Arrangement of core zones, charge groups and side reflector.

Pressure-vessel considerations limited, to a large extent, the size of the reactor core and calculations indicated that minimum fuel diameters and lattice pitch were 1.1 in. and 7½ in. respectively. Subsequently, the values adopted were 1.15 in. and 8 in. Originally it was envisaged that there would be two zones in the reactor, the outer of which was composed of enriched material; but the improved data caused a change in policy which resulted in the adoption of three zones, all of which would be fed by natural uranium, although, again, enriched uranium would be available if the calculation proved to be optimistic in practice. The paper reviews the series of calculations that were performed to determine the optimum characteristics, including the selection of channel diameters which ranged from 4.16 in. in zone A to 3.95 in. in zone B and 3.61 in. in zone C. To equalize further temperature distribution, each channel is provided with a gag and coolant flow and zone areas have been based on the use of zero-gag sizes at the innermost groups of zone A and B.

LATTICE CONSTANTS AT THE OPERATING TEMPERATURES WITH NATURAL URANIUM FUEL AND FILLED WITH CARBON DIOXIDE

Average uranium temperature=425°C Average graphite temperature=250°C

Constant	Zone A	Core Zone B	Zone C	Reflectors Top Reflector	Bottom Reflector	Side Reflector
Inner radius, ft.	0	6.02	10.85	3.25*	2.67*	15.49
Outer radius, ft.	6.02	10.85	15.49	—	—	18.00
Channel diameter, in. ...	4.16	3.95	3.61	—	—	—
Number of channels	256	576	864	—	—	—
Thermal utilization factor, f ...	0.93186	0.93010	0.92672	—	—	—
Resonance escape factor, p ...	0.87533	0.87861	0.88398	—	—	—
Fast fission factor, ϵ	1.02972	1.02972	1.02972	—	—	—
Thermal fission factor, η ...	1.26595	1.26595	1.26595	—	—	—
Multiplication constant, $k\infty$ ...	1.06330	1.06527	1.06789	—	—	—
Radial diffusion area, cm^2 ...	406.6	391.9	371.1	7,519.7	3,765.1	3,422.4
Axial diffusion area, cm^2 ...	464.6	438.9	403.6	9,340.7	4,227.4	3,422.4
Radial slowing-down area, cm^2	628.9	588.6	528.1	803.3	640.6	387.0
Axial slowing-down area, cm^2	709.5	652.7	570.6	962.1	703.2	387.0

* Thickness of reflector quoted.

Early Metallurgical Prob'ems *by R. A. U. Huddle, M.A. (head of corrosion section, A.E.R.E.) and L. M. Wyatt, M.A., F.I.M. (fuel element technology, A.E.R.E.)* and **Metallurgical Developments** *by L. Granger, B.Sc. (assistant director, metallurgy section, Risley) and A. B. McIntosh, B.Sc., Ph.D., F.R.I.C., F.I.M. (head of research and development laboratories, Culcheth).*

The first of these two papers describes preliminary work carried out at A.E.R.E., Harwell, up to the end of the design study, while the second describes the development work after the project had been transferred to the Research and Development Branch of the Industrial Group at Risley. The two papers have been considered here together to eliminate overlapping, since a considerable amount of work went on at Harwell after the transfer of the project.

A very considerable amount of effort was devoted to the fuel element and its canning, the dimensional stability of uranium under irradiation and thermal cycling presenting many problems in the production of bars which would not be subject to bowing or dog-leg distortion. It was discovered that fine grain metal with random crystal orientation—the only method of overcoming this distortion—could be obtained by quenching in water from 750°C. The uranium bars were produced by vacuum casting in graphite moulds; steel moulds chromium-plated are also suitable. Heat treatment for grain refining was found to present more difficulties following on improvement in the purity of the uranium, and it was found necessary to institute impurity adjustments on every individual billet of uranium. Ex-

tremely careful alignment of the induction-type heat-treating gear was found to be important.

A wide range of work was carried out on canning materials, since most metals had some obvious defect, such as a tendency to alloy with uranium, forming low-melting-point eutectics. Magnesium appeared to be free from any tendency to react with uranium, and it was originally intended to proceed with high-purity magnesium, but a series of alloys known as Magnox showed improved corrosion resistance. Early work, however, showed that weld cracking occurred. This was shown to be due to the calcium content, and the final choice fell on an alloy known as Magnox "C" (the actual composition of this alloy is not stated, but it is said to contain no calcium).

The mechanical details of the can, too, were interesting. It was originally intended to fabricate cans by a thread-rolling process similar to the Integron finned tube, but it was felt that time was too short to be certain of developing sufficiently high and fine finning, so that the actual method undertaken involved machining from the solid, thick-walled extruded tube being ruled out due to the difficulty of obtaining a straight bore.

The final process involved forcing the can under pressure into grooves in the uranium bar in order to prevent ratcheting under thermal cycling. The can lids were made by an impact extrusion process from rolled sheet; the lids were then welded on by argonarc welding. Included in the finished can was a capsule of helium which burst on heating, and can be used in conjunction with a mass spectrometer for testing the absolute soundness of the container. During the developments of manufacturing methods, a complete prototype canning line was set up in the Research and Development branch, which carried out many thousands of unit operations and actually produced some 200 complete fuel elements.

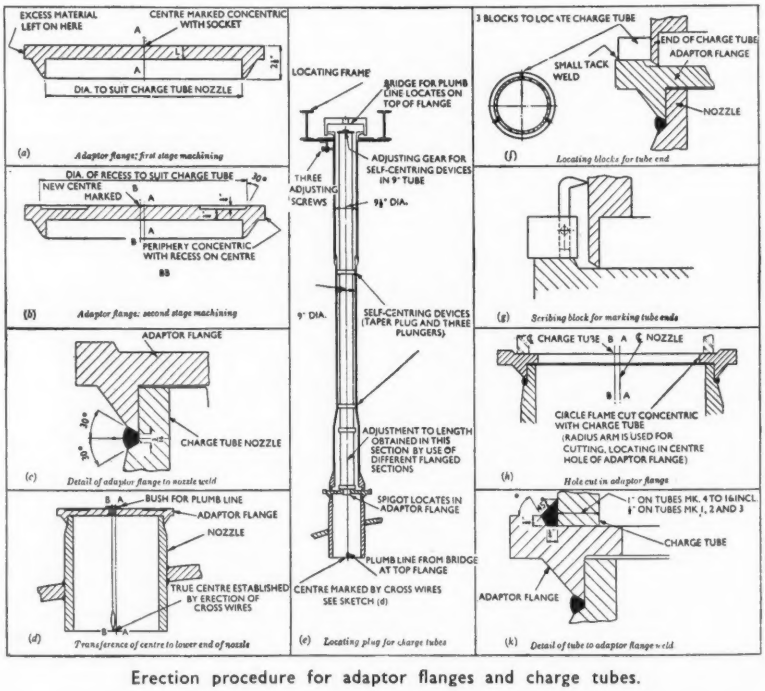
Tests on suitable steels for the pressure vessel showed that, so far as oxidation at elevated temperatures in CO_2 under pressure goes, most mild and low-alloy steels may be used without anything more than a slightly-adherent non-flaking scale being formed. Other requirements necessitated freedom from brittle fracture, creep, or long-term creep-rupture. Work done in this field has been very much with an eye to the future.

SESSION 3—FRIDAY, NOVEMBER 23

ENGINEERING DESIGN

Design and Construction of Reactor Vessel *by G. Brown, B.Sc., (Eng.), Ph.D., A.M.I.Mech.E., M. J. Noone, M.I.Mech.E., and R. F. Bishop, M.A., A.M.I.Mech.E. (chief engineer, thermal reactor design office, A.E.A., Risley; director and manager of operations, Whessoe Ltd.; and chief engineer, special developments, Whessoe Ltd.)*

One of the most interesting portions of this paper is that dealing with the extraordinary precautions taken to ensure alignment of the charge tubes. It was laid down that the centre of the bottom end of the 9-in. diameter portion should lie within an $\frac{1}{8}$-in. circle of its true position; the tilt from this point to the centre of the top flange should not exceed $\frac{3}{16}$ in. and the top flange should lie within $\frac{1}{8}$ in. of the true height. This was achieved by the use of adaptor plates machined to fit the nozzles in the top dome, and after temporary tack-welding and match-marking were centre-marked from templates. The plates were then removed, and the recess for the charge tube machined to this new centre and the adaptor plates replaced and welded into position. After pressure-testing of the vessel, a further survey was taken and centres re-marked where necessary, holes being drilled to take the spigot of a locating plug. The centre of the hole was then transferred to cross-wires at the bottom of the nozzle. A locating plug, provided with an adjustment for height, was then placed in position and plumbed to these cross-wires from a bridge at the top of the tube flange, and the position of the tube located by three small blocks tack-welded in position. The tube was then cut to length, the hole in the flange flame-cut and dressed, and the tube re-erected and welded into position, the blocks being removed as welding proceeded. For the four 6-in. irradiation tubes the accuracy required was not so critical and spigot-type joints were considered satisfactory.

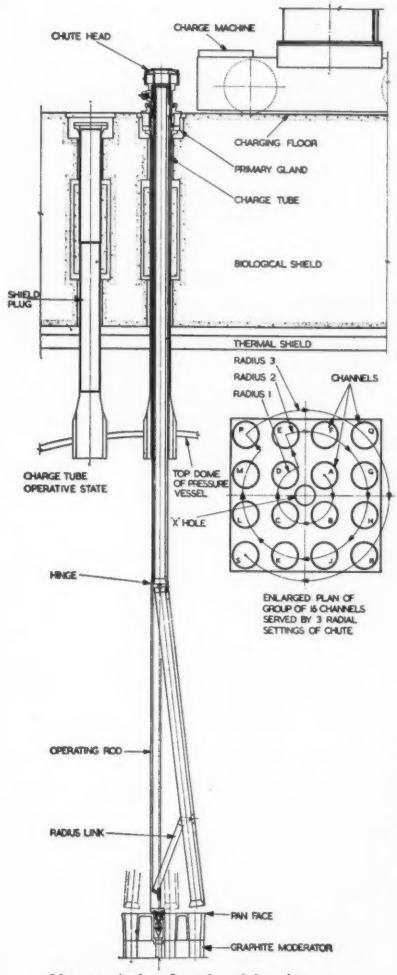

EXCESS MATERIAL LEFT ON HERE
CENTRE MARKED CONCENTRIC WITH SOCKET
DIA. TO SUIT CHARGE TUBE NOZZLE
(a) Adaptor flange; first stage machining
DIA. OF RECESS TO SUIT CHARGE TUBE
NEW CENTRE MARKED
PERIPHERY CONCENTRIC WITH RECESS ON CENTRE
(b) Adaptor flange; second stage machining
ADAPTOR FLANGE
CHARGE TUBE NOZZLE
(c) Detail of adaptor flange to nozzle weld
BUSH FOR PLUMB LINE
ADAPTOR FLANGE
NOZZLE
TRUE CENTRE ESTABLISHED BY ERECTION OF CROSS WIRES
(d) Transference of centre to lower end of nozzle
LOCATING FRAME
BRIDGE FOR PLUMB LINE LOCATES ON TOP OF FLANGE
ADJUSTING GEAR FOR SELF-CENTRING DEVICES IN 9" TUBE
THREE ADJUSTING SCREWS
9⅛" DIA.
9" DIA.
SELF-CENTRING DEVICES (TAPER PLUG AND THREE PLUNGERS)
ADJUSTMENT TO LENGTH OBTAINED IN THIS SECTION BY USE OF DIFFERENT FLANGED SECTIONS
SPIGOT LOCATES IN ADAPTOR FLANGE
PLUMB LINE FROM BRIDGE AT TOP FLANGE
CENTRE MARKED BY CROSS WIRES SEE SKETCH (d)
(e) Locating plug for charge tubes
3 BLOCKS TO LOCATE CHARGE TUBE
END OF CHARGE TUBE
ADAPTOR FLANGE
SMALL TACK WELD
NOZZLE
(f) Locating blocks for tube end
(g) Scribing block for marking tube ends
℄ CHARGE TUBE
B A
℄ NOZZLE
CIRCLE FLAME CUT CONCENTRIC WITH CHARGE TUBE (RADIUS ARM IS USED FOR CUTTING, LOCATING IN CENTRE HOLE OF ADAPTOR FLANGE)
(h) Hole cut in adaptor flange
1" ON TUBES MK. 4 TO 16 INCL.
¾" ON TUBES MK. 1, 2 AND 3
CHARGE TUBE
ADAPTOR FLANGE
(k) Detail of tube to adaptor flange weld

Erection procedure for adaptor flanges and charge tubes.

In addition to these, the vessel is fitted with eight sampling-tube nozzles of 12 in. diameter and four tubes of 3 in. diameter for thermocouples, eight 1-in. tubes for measurement of graphite growth and a 6-in. viewing tube for introscope or T.V. camera. Generally speaking, the accuracy and workmanship obtained throughout appears almost phenomenal when the size and massive construction of the vessel are considered. The final diametral accuracy was within $\pm\frac{1}{2}$ in. and the accuracy on the overall length $-\frac{5}{8}$ in. The amount of welding cut out and re-welded averaged $1\frac{3}{4}\%$.

Uranium Fuel Handling *by K. H. Dent, A.M.I.Mech.E., and G. W. Grossmith, M.C., M.I.Mech.E. (assistant chief engineer, thermal reactor design office, U.K.A.E.A., Risley; and managing director, Strachan and Henshaw Ltd.)*

The introduction of pressure gas cooling, with its containing vessel, made the simplification of the charge and discharge arrangements difficult to achieve. The



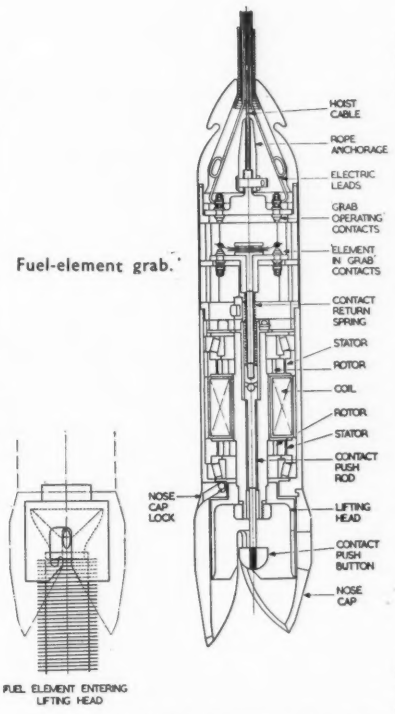
Charge hole fitted with chute ready for recharging.

principle was adopted, therefore, of shutting down and de-pressurizing the reactor to discharge large quantities of metal at infrequent intervals. No mechanism or moving parts are built into the reactor core or in any location subject to radiation.

During recharging, the coolant is maintained at about 150°C at the outlet end of the reactor, at which temperature the differential expansions are reduced to manageable proportions. Also, the CO_2 pressure at the top of the reactor is maintained at about 2 in. W.G. above atmospheric pressure by manually-operated valves on the charge floor. This permits the introduction of the charge chute into the pressure vessel through rubber glands, giving temporary sealing without the need for high-pressure gas locks. Precautions taken against the possibility of gas outleakage are described.

The equipment comprises two charge machines, two discharge machines, a traverser, charge chutes, well hoist and o.h.c. The machines operate in pairs of one charge and one discharge. The time to load or unload four channels (24 fuel elements) is about 35 min., giving a turn-round time of 70 min. for each machine.

For recharging operations, the charge hole is prepared and a charge chute, 30 ft.



long with a hinged lower section of variable radius, inserted. A discharge machine ready purged and filled with clean CO_2 is positioned over the chute head and a sealing member lowered to form a gas-tight passage. One chute serves 16 channels by three radial settings. An electrically-operated grab is lowered and engaged with a fuel element, which is then lifted and deposited within the rotary basket on the machine. The basket holds 24 elements from four channels.

The grabs are 45 V, D.C., with homopolar square-tooth rotor-stator unit, having a limited angular movement of 17 degrees. When energized, three bayonet slots in the lifting head are in line with slots in the nose cap. These slots engage the three-armed spider on the top of a fuel element. On contact being made, the presence of the element is signalled and the grab closed. Hoisting is by an A.C. commutator motor with a speed range at the grab of 20-200 ft./min. The baskets are rotated within the machine, whilst the elements are deflected laterally in the discharge basket by a hydraulic plunger so as to rest on the lip at the base.

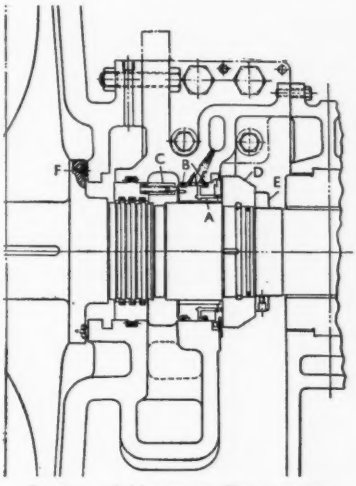
In every group of 16 channels there is one top element fitted with a thermocouple which needs special handling gear.

In the event of a fuel element failing to discharge, the channel in which it lies may be examined by a television camera.

The m.p.l. of whole body gamma radiation has been set at 0.3 r/week and the discharge plant has been designed so that no operator receives an average of more than one-third of this.

Design of Important Plant Items *by A. T. Bowden, B.Sc. (Eng.), Ph.D., M.I.Mech.E., and G. H. Martin, M.I.Mech.E., A.M.I.E.E. (director and chief research engineer, and chief project engineer, C. A. Parsons Ltd.)*

One of the most interesting features of this paper is the oil-seal arrangement for the shaft of the main gas circulators. The main running seal takes place between a nitrided collar (D) and a spring-loaded



Section of blower sealing system.

floating ring (A) faced with white metal. The floating ring is sealed to the casing by two rubber packing rings and oil is admitted between these rings at a pressure (maintained by a differential control valve) about 5 lb./sq. in. above the gas pressure, being admitted to an annulus on the seal face by radial and axial passages. Radial grooves from this annulus allow about 99.9% of the oil to escape to an atmospheric drain, while the small amount of oil flowing inwards drains to a pressurized detraining tank, from which it is released by a float valve to an atmospheric degasifying tank. The quantity flowing in this way in normal full-pressure operation is about 1 gal./hr. and the loss of CO_2 which is released to atmosphere is about 5 lb./day. There is a labyrinth gland of conventional design to reduce the flow into the casing if the inner seal ring fails and to prevent the back diffusion of oil vapour into the main gas stream.

For the servicing of this seal it is possible to provide a stand-still seal. At point F there are two machined faces with silicone-rubber seals that normally run clear. When servicing is required, the rotor of the blower is displaced by the thrust-adjusting gear until this seal is pulled up tight. There is a removable section in the shaft between the blower and the motor, so that the floating collar can be removed with the minimum of disturbance. If it is merely required to replace the sealing rings it is not necessary to remove the shaft section, since there is a container carrying spare rings already threaded on the shaft. The shaft is, of course, fitted with jacking gear so that the bearings can be removed as required.

Steam Cycle Analysis *by W. R. Wootton (assistant manager, atomic energy department, Babcock and Wilcox Ltd.)*

This paper summarizes briefly the vast amount of work that went into the investigation of the steam cycle from as far back

as 1948. (The evolution of the particular conditions obtaining at Calder Hall was described in *Nuclear Engineering* for October, and it seems unnecessary to repeat them. There are, however, two points in the paper which deserve to be reported verbatim, since they are fundamental not only to Calder Hall but to nuclear power stations in general.) In his introduction, the author says: "With conventional steam power plant, an increase in capital costs per kilowatt installed can be justified if the gain in efficiency is sufficient, because the fuel cost is the greatest fraction of the total cost of generation. With nuclear power plant, the reverse is the case, the effect of efficiency on the total cost of generation being less."

In his conclusion, the author points out that: "The steam-cycle conditions adopted at Calder Hall may not be the best from a purely theoretical viewpoint, but are very close to the optimum when the many overriding practical considerations are taken into account. In future developments, many of these practical issues will be resolved and the way will be opened for greatly improved steam-cycle conditions. The multiple-pressure steam cycle is sensitive to reactor-coolant outlet temperature and modest improvements in the latter will bring rapid increase in efficiency. In the foreseeable future, its application promises to be competitive on economic grounds with any other cycle, however high the permissible fuel temperature may be raised through metallurgical and technological advancement."

Design and Construction of the Heat Exchangers *by H. Morris, M.I.Mech.E., M.I.E.E., M.Inst.F., and W. R. Wootton (chief engineer (production reactors), A.E.A., Risley, and assistant manager, atomic energy department, Babcock and Wilcox Ltd.)*

(The general construction of the heat exchangers has already been reviewed in these pages, but one or two additional details may be of interest.)

Instrumentation was kept to a minimum; but, bearing in mind that the plant was, as it were, a prototype, a certain amount was considered necessary, and the pump-house was provided with pressure gauges for H.P. and L.P. superheater outlets, main and auxiliary feed lines and differential pressure across the forced-circulation pumps. In addition, remote water levels for H.P. and L.P. drums were shown, while on one heat exchanger only, indicating thermometers were provided for CO_2 temperature at each tube bank. Alarms for high or low water level in each drum, loss of feed pressures and circulating pump failures were also provided in the circulator houses, this being the nearest, continuously-manned position. In addition, grouped alarms were provided in the main control room. Permanent measuring devices have also been installed for the metering of flows, pressures and temperatures for heat-balance measurements, and thermometer pockets and spacers (to be replaced by standard orifices) are installed for test purposes in the individual branches of the heat exchangers. Portable equipment is also provided for checking on the possibility of carry-over to the turbines.

Particular attention is paid to feed-water purity, and continuous observation is kept for the possibility of raw water leakage into the cooling system, water purity indicators being provided in the condensate lines after each turbine and dump condenser, together with oxygen recorders in each feed system to analyse condensate before and after the de-aerators.

The possibility—in spite of the extreme precautions taken—of CO_2 leaking into the L.P. system or H.P. steam leaking into the CO_2 must be faced, and infra-red gas analysers are used for the detection of CO_2, one being installed to monitor the gas in the heat exchanger continuously. The L.P. system has an analyser which operates on air passed through a chamber containing L.P. condensate, and which will pick up any CO_2 contained therein. The air is first passed through a chamber containing soda asbestos to remove its normal atmospheric CO_2 content before being passed through the condensate chamber and the analyser.

SESSION 4—FRIDAY, NOVEMBER 23

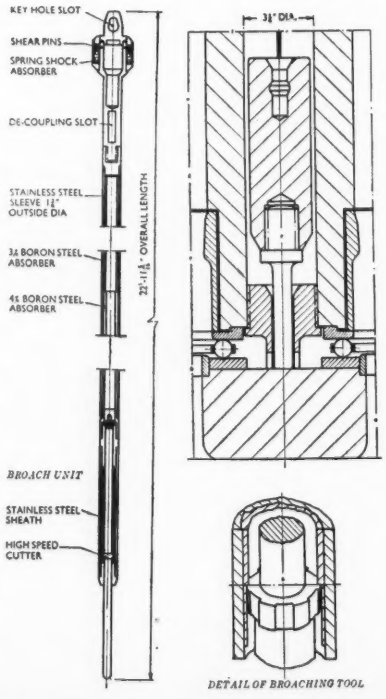
LIGHT ENGINEERING AND ELECTRICAL

Equipment for Control of the Reactor *by S. A. Ghalib, B.Sc., M.I.Mech.E., M.I.E.E., and J. H. Bowen, B.Sc., A.M.I.E. (chief engineer, A.E.I.-John Thompson Nuclear Energy Co. Ltd., and assistant chief engineer, U.K.A.E.A., Risley)*

Outlining the performance requirements, the authors discuss briefly the function, form, capacity and duties of control elements before dealing with structural considerations and working conditions in the Calder Hall reactor. These decided that the absorber would be in rod form; that its length would be 22 ft.; that the drive would be through the charge tubes; and that as much as possible of the assembly should be kept on the inactive side of the shield plug. The choice of the system adopted was made by analyses backed by practical tests, of lubricants, metals, linkage systems and driving mechanisms.

Iron castings were chosen for the driving head, whilst for the control rod a special stainless steel sheath was developed containing less than 0.02% cobalt and acting as a structural member. The 10% boron-steel alloy absorbing material is in the form of short tubular inserts with wall thicknesses ranging from $\frac{1}{4}$ in. at the bottom of the rod to $\frac{1}{8}$ in. at the top: a 3% alloy was found suitable for the top inserts.

As shown in the figure, the cable is attached to the top of the rod in such a way that its removal from a remote position



Arrangement of control rod and impact stool.

is relatively simple. A spring shock-absorber is provided, which supports the rod in the normal lowered position with the top resting on the charge pan. In normal operation, including emergency shut-down, the terminal velocity of the control rod is less than 6 in./sec., and the spring cushions the final impact. Should the cable break, the force of impact on the charge pan is limited to 300 lb. by shear pins. The rod continues to fall and its kinetic energy is absorbed by a broaching device at the bottom end of the rod. The length of the cutting stroke may be varied by adjusting the cutting depth, and to keep this constant over many years the metal of the cutter and sleeve were selected to resist corrosion.

The figure also shows the restrictor, which limits the flow of coolant gas through a control-rod channel, so as not to reduce significantly the bulk gas temperature, and to save gas pumping power. Should the reactor pressure vessel or circuit suffer a burst, the design of the restrictor would not allow the pressure difference to cause it to rise in the channel and jam a control rod. Similarly, the control rod and channel proportions preclude the control rod being blown out.

A synchronous motor drives a winch drum through 20:1 gearing. An eddy-current brake controls the speed in emergency shut-down operations, a solenoid-operated dog clutch releasing in these conditions to avoid back-driving the motor. Speed and direction are controlled

The World's Reactors
No. 6—CALDER HALL

The following parameters and performance data are compiled from papers given at the British Nuclear Energy Conference Symposium on the Calder Works Nuclear Power Station on November 22-23, 1956, and supersede the interim data given in "The World's Reactors—No. 6" published in the October, 1956, issue.

TYPE: Thermal heterogeneous.

PURPOSE: Plutonium production.
Power production.
Prototype for central power stations.

LOCATION: Sellafield, Cumberland, England.

CAPACITY: Maximum electrical rating: 184 MW from four reactors and eight turbo-alternator sets.
Electrical output: 21 MW per turbo-alternator set.
Feed-back: 7.5 MW per reactor.
Distribution to grid: 132 kV.
Internal distribution: 11 kV, 3.3 kV and 415 V.
Heat rating: 182 MW.

OPERATION: Diverged May, 1956.
Opened by H.M. Queen Elizabeth, October 17, 1956.

FUEL: Natural uranium.
U as cast bars 1.15 in. dia., 40 in. long.
Density: 18.7 g/cm³.
Elements in vertical channels: six per channel.
Total weight of fissile material: 120 tonnes per reactor.
Number of fuel-element channels: 1,696.
Diameter of channels: 256 at 4.16 in.
576 at 3.95 in.
864 at 3.61 in.
Average temperature: 425°C.

CANNING: Magnesium alloy—Magnox C, He filled.
Wall thickness: 0.072 in.
Diameter: 1.30 in.
Extended surface: single-start helical fin 0.125 in. pitch.
Overall diameter: 2.125 in.
Design maximum can surface temperature: 408° C.

MODERATOR: Graphite.
Core size: 21 ft. high, 31 ft. dia.
Overall size including reflector: 24-sided regular prism, 27 ft. high, 36 ft. across corners.
Total weight: 1,146 tons.
Blocks 8 in. sq., 25 in. long.
Each column supported by ball bearings on 4-in. plates resting on diagrid.
Average temperature: 250°C.

LATTICE: Regular square, 8 in. pitch.

	Core		
	Zone A	Zone B	Zone C
Inner radius, ft.:	0	6.02	10.85
Outer radius, ft.:	6.02	10.85	15.49
Channel diameter, in.:	4.16	3.95	3.61
Number of channels:	256	576	864
Thermal utilization factor, f:	0.93186	0.93010	0.92672
Resonance escape factor, p:	0.87533	0.87861	0.88398
Fast fission factor, ϵ:	1.02972	1.02972	1.02972
Thermal fission factor, η:	1.26595	1.26595	1.26595
Multiplication constant, k_∞:	1.06330	1.06527	1.06789
Radial diffusion area, cm²:	406.6	391.9	371.1
Axial diffusion area, cm²:	464.6	438.9	403.6
Radial slowing-down area, cm²:	628.9	588.6	528.1
Axial slowing-down area, cm²:	709.5	652.7	570.6

PRESSURE VESSEL: 2-in.-t
37 ft.
Desig

COOLANT: Carbo
Work
Flow:
Inlet
Outle
Numl
Diam
Mean
74

PUMPING: Four
Mass
Circu
Isent
Com
Speed
Powe

CONTROL: Numl
Diam
Coar
Fine:
Norm
Rod
Leng
Suspe
0.0
Drive
In sp
Shut-

REACTIVITY: Total
Cent
Incre

SHIELDING: Ther
Biolo

Cool

HEAT EXCHANGERS: Num
Main
I.D
Gas
Stea
Head
Econ
Boile
Supe
Gas
Tota
Heati
Outs
H.P.
H.P.

PRESSURE VESSEL:

2-in.-thick Lowtem Al-kill mild steel, fusion welded.
37 ft. inside diameter, 70 ft. high.
Design stress at 400°C: 1,200 lb./in.^{2}

COOLANT:

Carbon dioxide circulated upwards through reactor.
Working pressure: 100 p.s.i.g.
Flow: 1,964 lb./sec. (2,160 lb./sec. maximum).
Inlet temperature: 140°C.
Outlet temperature: 336°C.
Number of ducts: four.
Diameter of ducts: 4 ft. 6 in.
Mean coolant velocity: (cool ducts) 49 ft./sec.; (hot ducts) 74 ft./sec.

PUMPING:

Four centrifugal blowers, one in each heat-exchanger circuit.
Mass flow in each circulator: 500 lb./sec. (550 lb./sec. maximum)
Circuit pressure drop: 5.53 p.s.i. (6.69 p.s.i. maximum).
Isentropic efficiency at design point: 78%.
Compression power: 1,497 b.h.p.
Speed control: Ward-Leonard type, range 10:1.
Power required (four circulators): 5.44 MW.

CONTROL:

Number of channels: 112.
Diameter of channels: 3.25 in.
Coarse: up to 60 rods ganged together.
Fine: up to four, manually operated.
Normal operation: total of 40 rods.
Rod construction: boron steel in 18/8/1 stainless steel sheath.
Length: 22 ft.
Suspension: stainless steel cable (seven strands, each of 19 wires 0.010 in. 18/8 stainless steel EN 58).
Drive: synchronous motor and winch, 20:1 gearing.
In speed: 5 in./min. and 50 in./min. Out speed: $\frac{1}{2}$ in./min.
Shut-down speed: 4 ft./sec. (6 in./sec. for last 2 ft. 6in. of travel).

REACTIVITY:

Total excess: 4%.
Central channel increment: 0.015%.
Increment per control rod: $\sim$ 0.2%.

SHIELDING:

Thermal: 6-in. thick steel plates.
Biological: concrete, 7 ft. on sides, 8 ft. on top.
density, 150 lb./ft.^{3} minimum, 160 lb./ft.^{3} av.
octagon, 60 ft. across flats, 90 ft. high.
total weight on foundations, 33,000 tons.
Cooling: blown air.

HEAT EXCHANGERS:

Number per reactor: four.
Main shell: 73 ft. 4 in. over flanges; 77 ft. 4 in. overall; 17 ft. 3 in. I.D.; thickness $1\frac{5}{16}$ in.
Gas inlet: 6 ft. dia. Gas outlet: 4 ft. 6 in. dia.
Steam drums: length 19 ft. $7\frac{7}{8}$ in.; 4 ft. I.D.; thickness $\frac{11}{16}$ in.
Headers: $10\frac{1}{4}$ in. O.D.; thickness 1 in.
Economizer tubes: $1\frac{1}{2}$ in. O.D. × 8 S.W.G.
Boiler tubes: 2 in. O.D. × 7 S.W.G.
Superheater tubes: 2 in. O.D. × 6 S.W.G.
Gas volume: (live) 7,370 ft.^{3}; (dead) 6,600 ft.^{3}
Total gas volume: 13,970 ft.^{3}
Heating surface areas per heat exchanger:—
Outside of tubes in live gas:
H.P. superheater 4,450 ft.^{2}; L.P. superheater 785 ft.^{2}
H.P. superheater 31,500 ft.^{2}; L.P. superheater 31,500 ft.^{2}

HEAT
EXCHAN
(Contin

TURBO-
ALTERNA

COOLIN
TOWERS

*A limited s
reactors bu
publishers,
packing and*

HEAT EXCHANGERS: *(Continued)*

H.P. H.T. econ. 15,750 ft.^{2}; L.P. H.P. econ. 15,750 ft.^{2}
Total: 99,735 ft.^{2}
Inside of tubes in live gas:
H.P. superheater 3,580 ft.^{2}; L.P. superheater 632 ft.^{2}
H.P. evaporator 5,886 ft.^{2}; L.P. evaporator 5,886 ft.^{2}
H.P. H.T. econ. 3,304 ft.^{2}; L.P. H.P. econ. 3,304 ft.^{2}
Total 22,592 ft.^{2}

Length of tubes per heat exchanger:—

H.P. superheater 152 ft. 6 in. per element, 9,764 ft. per bank.
H.P. evaporator 253 ft. 9 in. per element, 16,143 ft. per bank.
H.P. H.T. econ. 286 ft. 9 in. per element, 12,044 ft. per bank.
L.P. superheater 59 ft. 3 in. per element, 1,898 ft. per bank.
L.P. H.P. econ. 292 ft. 6 in. per element, 12,333 ft. per bank.
Total length 1½ in. O.D. tubing in banks: 24,378 ft.
Total length 2 in. O.D. tubing in banks: 43,949 ft.

Gas and steam conditions for one heat exchanger at full load:—

CO_2 gas flow-rate: 491 lb./sec.
Gas temperature at H.E. inlet: 336°C (637°F).
Gas temperature at H.E. outlet: 135°C (275°F).
H.P. steam flow-rate (77% total): 99,000 lb./h.
H.P. steam exit temperature: 595°F (313°C).
H.P. steam exit pressure: 210 p.s.i.a.
H.P. steam exit enthalpy: 1,318.3 B.t.u./lb.
Power of H.P. circulating pump: 40 h.p.
L.P. steam flow-rate (23% total): 29,650 lb./hr.
L.P. steam exit temperature: 350°F (171°C).
L.P. steam exit pressure: 62.7 p.s.i.a.
L.P. steam exit enthalpy: 1,207.4 B.t.u./lb.
Power of L.P. circulating pump: 12.5 h.p.
Feed-water pressure at H.E. inlet: 340 p.s.i.a
Feed-water temperature at H.E. inlet: 100°F (37.8°C).
Feed-water enthalpy at H.E. inlet: 68.9 B.t.u./lb.
Feed-water flow-rate: 128,650 lb./hr. (plus losses).
Heat taken up by water and steam: 46.15 MW.

TURBO-ALTERNATORS:

Number of sets per reactor: two.
Maximum continuous rating: 23 MW at a power factor of 0.8 lagging.
Speed: 3,000 r.p.m.
Generator voltage: 11.5 kV, three-phase, 50 c/s.
High-pressure steam pressure at turbine stop-valve: 200 p.s.i.a.
High-pressure steam temperature at T.S.V.: 310°C.
High-pressure steam per set (77% total): 198,000 lb./hr.
Low-pressure steam pressure at T.S.V.: 53 p.s.i.a.
Low-pressure steam per set (23% total): 59,300 lb./hr.
Output: 21 MW.
Flow-rate to condenser per set: 257,300 lb./hr.
Maximum cooling water temperature: 29.4°C.

COOLING TOWERS:

Two, serving two reactors.
Half-basin capacity: 687,500 gal.
Cooling range: 30.5°C to 21.1°C.
Wet-bulb temperature: 8.3°C.
Dry-bulb temperature (humidity 60%): 11.1°C.
Tower height above sill: 290 ft.
Tower diameter at ring beam: 200 ft.
Throat diameter: 104 ft.

A limited supply of separate copies is available of this series of data sheets on various reactors built or projected throughout the world. Copies may be obtained from the publishers, Temple Press Limited, Bowling Green Lane, London, E.C.1, at the cost of packing and postage only (4d. each).

by the electrical supply to the motor, A.C. current at 0.0133, 0.13 and 1.3 c/s at 40 V (root mean square) being supplied.

The integrity of the biological shield is restored by shield plugs fitting inside the charge tubes. A plug comprises a 4-in. thick steel slab which locally acts as a thermal shield and a concrete-filled cylinder divided into two vertical sections. In addition to the cable-way through the plug, a rod passes down to operate a flap at the bottom. This is used when lifting a control rod completely clear of the core. Mechanical interlocks ensure that the flap is brought into use before the control rod can be lifted out and, conversely, that the flap is removed before normal operation.

Detection of Faulty Fuel Elements *by E. Lang, A.M.I.Mech.E., J. M. Laithwaite, B.A., A.M.I.Mech.E., and K. W. Cunningham, B.Sc. (assistant chief engineer, thermal reactor design office, U.K.A.E.A., Risley; industrial liaison engineering branch, U.K.A.E.A., Risley; and chief engineer, Plessey Nucleonics Ltd.)*

Six possible methods of detection were considered and the wire precipitator system was adopted. This method has the advantage of discrimination against unwanted counts, whilst sensitivity is further aided by the concentrated deposition of active particles on to a short length of wire which permits more efficient counting than when the particles are dispersed throughout the bulk of the gas sample.

Each of the eight detection units serves 212 channels by periodic sampling via the selection system. A small gas sample from each channel is cooled and filtered before passing to the detection unit. The filter removes all solid fission product atoms, leaving principally those of krypton and xenon, the presence of which indicates the exposure of uranium to the coolant.

The authors discuss the main parameters affecting the design and overall performance of the detection unit and give performance equations.

Difficulties associated with operation of the unit at pressure have been overcome by the use of a scintillation counter enabling the phosphor to act as a pressure window. Wire activity decays by a factor of about 10 in 20 min. background activity being kept low by storing an adequate amount of wire on the pulleys.

Counts arising from activity of the coolant are kept insignificant by filtration and precipitation and also by a slow purge of CO_2 in the region of the phosphor. Spurious counts arising from contamination are the major limitation to counting sensitivity. It is imperative, therefore, that the outside of the cans be thoroughly cleaned before dispatch to the reactor, and that burst cartridges be detected and discharged before contamination spreads.

To maintain accessibility of the stop-cocks and selector valves, it has been necessary to have about 60 ft. of sample piping between them and the reactor. Sample gas enters the detection room via 1,696 small-bore stainless steel pipes from the reactor channels and via eight pipes from the main ducts. It leaves via a single pipe to the compressors in the blower house. All pipe joints are made by inserting stainless steel ferrules with copper rings and fused in a special H.F. brazing head.

Within the vessel, the vertical pipe runs are kept as far away as possible from the axis of the charge pan (round which the charge mechanism rotates), i.e., at the corners of the pans. In the horizontal run the pipes are kept clear by cleating to a supporting framework suspended from the top of the pressure vessel, provision being made to permit free differential expansion between the girder structure and the pressure vessel.

The paper concludes with brief descriptions of the mechanical components, such as the selection system, cooling and filtration, counter, 54-point recorder and compressor.

Reactor Control and Instrumentation *by R. J. Cox, B.Sc., M.I.R.E., A.M.Brit.I.R.E., and K. R. Sandiford, B.Sc. (group director, reactor instrumentation group, A.E.R.E., Harwell, and Chief Instruments engineer, U.K.A.E.A., Risley)*

The instrumentation of the turbines and generators follows normal practice, but the instrumentation of reactor and heat exchangers includes techniques and equipment which are novel. The temptation to over-instrument the installation was large, and even after resisting the temptation the total number of instruments exceeds 2,500. These instruments cover the control of the reactor and the gas circuit, detection and location of faults and the initial adjustment of the plant and subsequent occasional adjustments.

The rate of production of heat is determined by the neutron flux. Adequate flux values can be obtained external to the core and the chambers have been mounted in a block of graphite 8 ft. wide by 5 ft. 4 in. high and 2 ft. 2 in. thick located outside the pressure vessel about mid-way up the core. At full power (180 MW) the slow neutron flux is approximately $3 \times 10^9 n/cm^2$-sec. Without priming, the power at shut-down would be about 0.4 mW, corresponding to a flux in the thermal column of $6 \times 10^{-3} n/cm^2$-sec. Four antimony-beryllium sources are introduced into the reactor, each of which consists of a tube of beryllium metal into which antimony is cast, the whole being encased in stainless steel. These photo-neutron sources decay with the half life of antimony-124, viz. 60 days, and serve to maintain the shut-down power level at a figure of about 2 watts, raising the neutron flux in the chambers to 30 n/cm^2-sec.

Due to the very large gamma-ray background immediately on shut-down, corresponding to 100 r/hr. for an unshielded chamber (this being reduced by a factor of 100 with 4 in. of lead), pulse detectors are required for low power operation. Two B 10 F_3 proportional counters feed through amplifiers and logarithmic count-rate meters and are of value up to a power level of a few kW. A shielded ion chamber of B 10 F_3, which immediately on shut-down would indicate a power of 30 watts and after 10 hours 3 watts, is used in conjunction with a logarithmic amplifier up to a power level of 1 MW. These three detectors are withdrawn into the biological shield during normal running to prevent over-exposure.

A further RC1 ionization chamber connected to a reactor period meter covers the range from a few hundred watts to full power. The logarithmic scale is of less value at higher power levels and the output, therefore, from the high-power ionization chamber is fed directly into a high-impedance self-balancing potentiometer recorder with a full scale range of either full power or 1/100 full power. A second chamber feeds a backed-off recorder to give drift power level and a further three chambers are connected to the shut-down amplifiers. The reactor shut-down operation is initiated by two coincident shut-down signals.

Control-rod position is indicated via magslip transmitters.

Coolant circuit and steam circuit conditions are indicated by flow rate and thermocouple temperature measurement of the CO_2 and the steam circuits.

Thermocouples also monitor the graphite temperature (which must be annealed periodically) and various points of the concrete structure and the cooling air.

Before the first start-up anemometric measurements were made of the gas flow in each of the channels, using vane-type anemometers and photo-transistor transmitters. Using 48 instruments, six men scanned all channels in three days.

Three types of safety and alarm circuit are in operation which shut the reactor down and give warning of fault conditions requiring immediate attention. The design of the safety circuits is based on the Post Office-type relay, tropically finished to provide the maximum security against failure. Supplies are obtained from a motor alternator driven continuously from a battery, with provision for automatic change-over to A.C. supply in the event of failure. Main contactors are slugged to allow this to take place without initiation of safety measures.

Four thermocouples distributed over the reactor allow regular checks to be made of fuel-element temperatures, whilst infra-red analysis permits continuous monitoring of CO_2 in the steam circuits and vice versa.

System Control and Protection *by E. Anderson, M.I.Mech.E., A.M.I.E.E., and J. H. Brown, B.Sc., A.M.I.E.E. (deputy chief engineer, Parolle Electrical Plant Co. Ltd., and assistant chief engineer, U.K.A.E.A., Risley)*

It is necessary to distinguish between operation of the plant on load and the special requirements of starting-up or shutting-down.

In equilibrium, the power from the system, of which part is reject heat, equals that generated by the reactor. Reactor power is regulated by a monitoring loop comprising power-measuring instruments and the reactor control rods. The loop is completed by a manual operator. By adjusting the lower steam pressure of the dual-pressure cycle, the operator may control the temperature at which the gas returns from the heat exchangers to the reactor, and by adjusting the speed of the main circulators he may control the temperature rise of the coolant gas for a given reactor heat rate. The circulators are provided with automatic speed regulators, so that in steady running it should only be necessary to adjust the position of

the control rods to compensate for self-induced drift in reactivity.

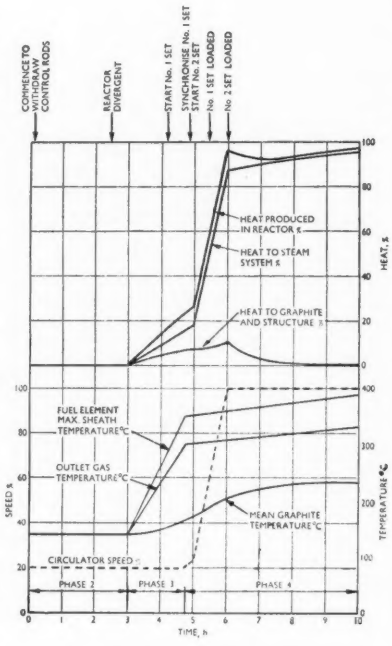
Pressure-sensitive valves regulate the pressure at which steam is generated, at a constant value on the H.P. system, and at a value, on the L.P. side, which may be adjusted from the reactor control room.

The starting-up process is summarized with reference to the considerations influencing the method and duration. For the more conventional items of plant,

System start-up characteristics.

acceptable temperature-rise rates may be laid down as a result of experience. With the pressure vessel and moderator structure, the only direct experience was from observations made when the vessel was pressure tested at elevated temperatures. From these it was decided to keep the grid at about 140°C, even when the reactor was shut-down. This is achieved by injecting steam from an external source into the drum heaters of the heat exchangers and running the circulators. It is then necessary to establish a temperature gradient of 200°C rising across the reactor.

The system requires cooling to 140°C on shut-down and this is achieved by first reducing reactor power at constant temperature, the turbines being off-loaded and heat removal continued with the dump condenser. The precautions necessary to deal with renewal of after-heat are dealt with.



Fault conditions causing a rise in temperature of the fuel elements required special attention, as failure of the fuel-element cans might contaminate the CO_2 pressure circuit. Circumstances causing a rise in power or reduced cooling capacity are dealt with, together with their effects and the steps taken in the design to limit their severity. A comprehensive system of interlocks and trips are provided to prevent these effects occurring. They are summarized in Table 1.

Table 1

Schedule of faults, trips and alarms

Fault	Component
Uncontrolled control-rod withdrawal (including regulating rods)	Shut-down amplifiers. Alarm on uranium-temperature recorders
Unrestricted control-rod withdrawal at start-up	Shut-down amplifiers. Reactivity trips
Accidental divergence when nominally shut-down	Low level trips. Reactivity trips. Shut-down amplifiers
Mal-operation of coolant flow	Shut-down amplifiers. Alarm on uranium-temperature recorder
Closure of main gate valves	Valve position alarm. Uranium - temperature alarm
Circulator-power failure	Trip from circuit breakers Shut-down amplifiers
Failure of single circulator	Flow comparator. Shut-down amplifiers
Pressure-vessel leak	Rate of change of pressure trip. Alarm on uranium-temperature recorder
Loss of feed water to heat exchangers	Alarm operated by feed pressure. Low water level alarms

SESSION 5—FRIDAY, NOVEMBER 23

FUTURE DEVELOPMENTS AND SUMMARY

Development of Gas-cooled Reactors for Power Production *by R. V. Moore, G.C., B.Sc. (Eng.), M.I.Mech.E., M.I.E.E. (assistant director, civil reactors, U.K.A.E.A., Risley)*

If the Calder plant was run as a power station and no value was attributed to the residual plutonium, it would produce electricity at about one penny per unit. This has been based on an interest and redemption of capital charged at 4% p.a., with an economic plant life of 20 years. The capital charges associated with the final figure represent about 50% of the total and burn-up has been taken as 3,000 MW days per ton, a figure now believed to be attainable.

Immediate improvements in the economics can be made by increasing the thickness, and hence the size, of the pressure vessel. Apart from the increase in heat-producing volume, a greater degree of flattening can be introduced which leads to further increases in the overall power output. Minimizing the heat output of the most highly rated fuel channel whilst improving the performance must be related to the pumping power. Raising the gas pressure gives only limited advantages and an increase of 50% is probably optimal. The simplified analysis, however, leads to a heat output from a single reactor with a 3-in. cylindrical pressure vessel of between 400 and 500 MW.

Raising the maximum fuel-element temperature increases the rating of the reactor and the overall efficiency of the plant, but to improve on the figure of 400°C to any marked extent involves the use of fuel elements clad in little-known metals and a change of fuel-element shape, probably necessitating the use of enriched fuel.

Calculations of fuel recycling are complicated by the formation from plutonium-239 of higher isotopes, of which whilst Pu 241 is fissile, Pu 240 and Pu 242 are not. Pu 242 has a highly adverse effect. Pu 243 decays almost immediately to Am 243, which would be removed in chemical processing. However, fuel recycling can reduce the natural uranium requirement by a significant factor and, under certain conditions, gas-cooled, graphite-moderated reactors requiring initially a charge of slightly enriched uranium can subsequently be fed with natural uranium.

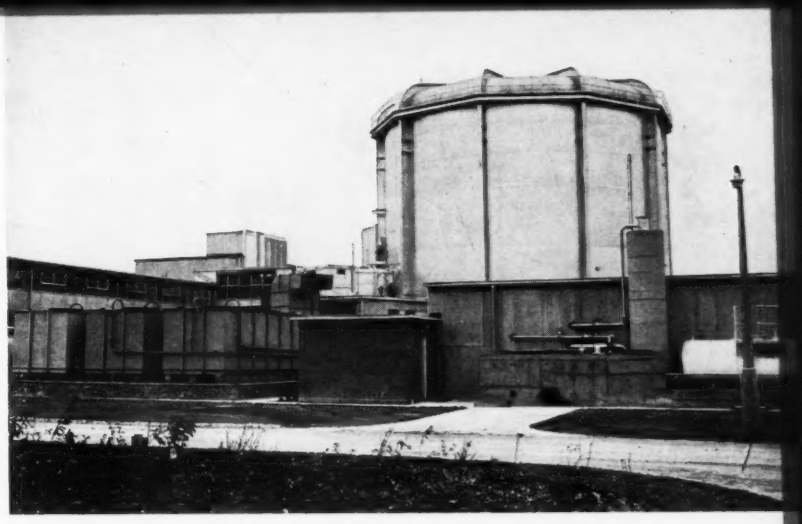
Alternative cooling gases are considered and, whereas hydrogen appears to offer marked advantages over, say, nitrogen, helium and carbon dioxide, practical considerations governing design of fuel-element surfaces make the advantages less marked. It is possible that, with increasing temperatures, helium or nitrogen could supplant CO_2 but the high reactivity of hydrogen would introduce considerable difficulties.

Non-metallic fuel elements are mentioned which, with the availability of enriched fuels, will become increasingly important.

The very high-temperature gas-cooled reactor using a highly enriched fuel (possibly pure) dissipated through the moderator offers distinct possibilities. With a gas-outlet temperature of 800°C, an overall efficiency of 40% could be achieved with the obvious improvement in economics. Whilst helium offers attractive possibilities as the coolant gas, the use of CO_2 would allow a reduction of two in the rotating machinery volume to be set against an increase of two in the heat-exchanger equipment. On total cost, however, CO_2 could be competitive, but design pressure for economic operation is liable to be considerably higher than 300 p.s.i.

DIDO

Opened on November 21, it will Provide High-flux Test Facilities



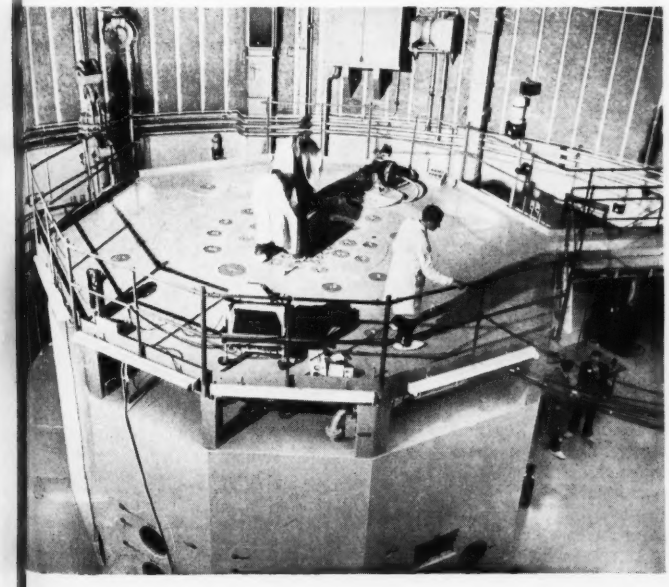
A general view of the outside of the DIDO building.

THE new deuterium moderated and cooled reactor DIDO was officially opened by Sir Cyril Hinshelwood, president of the Royal Society, on November 21. The reactor is the first of three to be built which will provide facilities for high flux testing of samples and loops and for the production of radio-isotopes. It has been built at Harwell on the land adjoining the main fenced-in establishment, whilst work on the second heavy-water reactor, PLUTO, is continuing alongside. The third, tentatively christened DEMETER, partly because of the name's mythological association with the god PLUTO and partly derived from DEuterium-moderated MatErials TEsting Reactor, is already under construction at Dounreay. DIDO is provided with eight thimble holes which penetrate the heavy-water tank and a single horizontal tube which passes right through. In addition, 18 tubes are provided which enter the reactor through the top plug. Numerous other holes are set in the graphite reflector and beam experiments can be conducted from the 5-ft.-sq. thermal column. The reactor has a full programme of work already mapped out, and various loops are in the course of manufacture for the testing of such unknowns as the corrosion of steel under high intensity radiation. Much of the initial work is likely to be of a metallurgical and chemical nature and the facilities for research that DIDO will provide will considerably speed the development programme for the more advanced reactors.

The core of DIDO is made up of 25 box-type elements, each containing nine plates of uranium aluminium alloy. Uranium used is highly enriched and the total investment is of the order of 2½ kg. The overall core dimensions are approximately 34 in.×28 in.×24 in. high. The lattice is basically square with the elements on a 6-in. pitch, but the centre row is displaced. The core is mounted in an aluminium tank of 80 in. diameter which, in turn, is surrounded by a graphite reflector with a radial thickness of approximately 20 in. The graphite is contained in a steel annulus lined with boral sheet on the inner face and filled with lead. The lead is water cooled by copper coils carrying distilled water. Outside the lead-steel shield is a concrete shield in the shape of an irregular decagon with overall dimensions approximately 25 ft.×19 ft. high. The heavy-water dump tanks and drying systems, etc., are housed below.

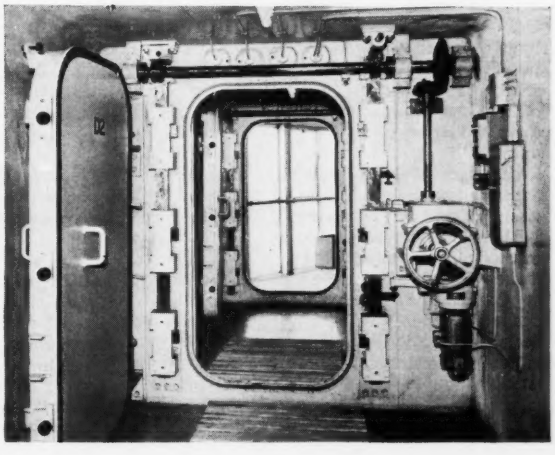
The assembly is built inside a containment shell, the in-between working area being accessible through airlocks and maintained at a pressure slightly below atmospheric. The core tank and some of the sealed sections of the reactor are pressurized to a little above atmospheric with helium, but all entries into the reactor sections are carefully sealed. Whilst serving to contain an excursion, if this should ever arise, the shell has been designed to withstand the internal negative pressure; the operating conditions are more severe, particularly when bearing in mind possible sudden changes in atmospheric pressure, than surge conditions which would arise in the event of an excursion. To ensure full containment, the floor of the building is plated with steel and these are welded to the side walls.

The reactor is controlled by signal-arm-type control rods, the height of the heavy water serving as a bulk control. A complex system of interlocks, however, which will be integrated with any loop experiments in progress, prevents mal-operation of the reactor.



(Left) The top of the reactor enclosure.

(Below) View through the personnel air lock.



Cæsium from Fission Products

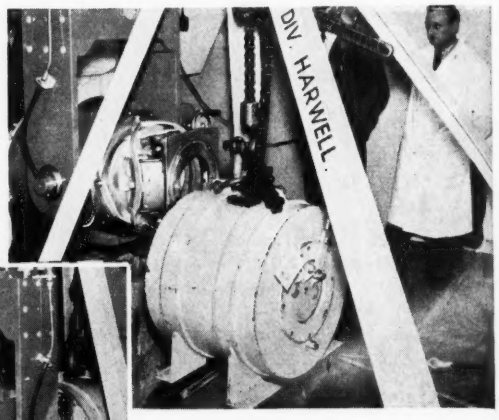
Waste from Windscale used for Cancer Therapy

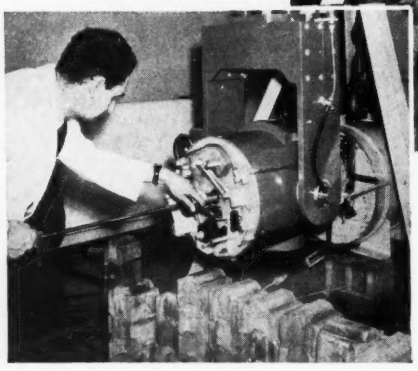
Britain's first production of cæsium-137 from fission products was recently delivered to the Royal Marsden Hospital, London, for deep-seated cancer therapy at a therapeutical unit at Sutton, Surrey. The operating unit has been designed in Professor Mayneord's department of physics in the Institute of Cancer Research by Dr. B. M. Wheatley, in association with Mr. E. M. Savage, of Bryant Symons and Co. Ltd., who built the unit.

This is the first unit of radioactive cæsium-137 to be prepared from fission products of the Windscale reactors, and is said to be the first time that this has been carried out in Britain. Its activity of 1,200 curies is believed, therefore, to be the third largest in the world. In 1954 Oak Ridge National Laboratory (operated by the Union Carbide and Carbon Corporation for the A.E.C.) produced a source of 1,540 curies, and a second unit of 2,000 curies was produced in July from the same laboratory. Cæsium is, of course, one of the most important of the long-lived gamma-ray emitters extracted from fission products, and a wide use is envisaged for many purposes.

Completing a 2,000-curie cæsium source in a remote-control cell at Oak Ridge.

There are interesting differences between methods of production here and in the United States. The method of production at Oak Ridge after processing to dry cæsium chloride was to compact the powder under heavy pressure (20,000 lb./sq. in.) into pellets which were then encapsulated in double-walled stainless steel containers. In the British method the salt was, we are informed, melted and poured into its capsule. The dimensions of the 2,000-curie source produced at Oak Ridge was 3.18 cm. diameter and 3.75 cm. high, and the British 1,200-curie unit 3 cm. diameter and 7 cm. long, made, incidentally, of platinum. This was shielded by a lead and uranium enclosure, which weighed nearly 1 ton, for transport purposes.





(Above) Lifting the British 1,200-curie unit in its 1-ton container to the level of the treatment unit.

(Left) Mr. W. S. Eastwood withdrawing the cæsium source into the therapy unit. The withdrawal rod is fixed to a protective cylinder of uranium screwed on to the source container.

In the treatment unit, the gamma rays emitted are defined by a novel form of shutter composed of curved plates of tungsten alloy moving round the surface of a sphere. The source is protected by uranium shielding, and both sides of the patient can be seen during treatment: one by direct view through a window and the other by means of a television camera set up on the far side of the room, showing on the screen in the treatment cubicle.

The original suggestion for the use of cæsium in this way was made by Mr. W. S. Eastwood of the Isotope Division at Harwell.

Nuclear Propulsion for Aircraft

Difficulties likely to arise in the application of nuclear propulsion to aircraft were reviewed in a paper by E. P. Hawthorne, B.A., A.M.I.Mech.E., A.F.R.Ae.S., before the Graduates and Students section of the Royal Aeronautical Society. In reviewing the main problems of size and weight, liquid-metal cooling appeared the only solution and the "first shot" contemplated was a fast reactor utilizing solid-fuel elements cooled by liquid metal. Regarding shielding, concrete and water seemed out of the question for aircraft and it would appear that shielding would consist of lead followed by alternate layers of boron, lithium and steel or lead. Even this, however, would produce a prohibitive weight and it might be possible to reduce the shielding in certain directions. It seemed that the minimum size of aircraft would weigh at least 150,000 lb. and might be twice as much.

A possibility to be considered would be the use of a "tug" aircraft, unmanned, which would reduce the shielding required, and to utilize conventional power plants for getting the main plane off the ground.

The most difficult problem of all, however, was that of accidents, which would inevitably release fission products, and the design and operation of the aircraft and the reactor would have to be considered chiefly from this angle.

Meetings to Note

December 5.—The Nuclear Engineering Society (Risley branch): "The Salesman's Problems in Providing Nuclear Power", G. Gordon Jackson (Mitchell Engineering Ltd.).

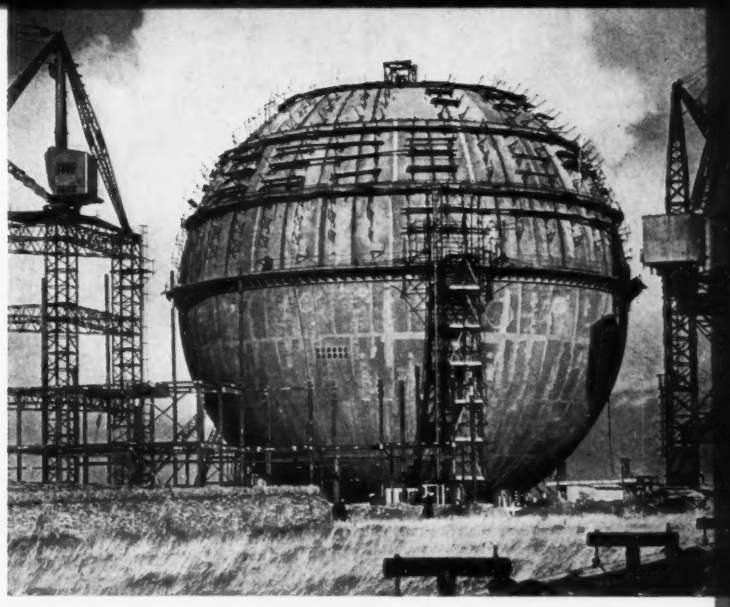
December 7.—University of London (at the London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1.): "The Development of Nuclear Power", R. V. Moore.

December 17-19. — Physical Society Autumn Meeting at Edinburgh University: "β and γ-ray Spectroscopy and Related Topics". Rutherford Lecture. Professor P. I. Dee, "The α Particle".

December 19. — Nuclear Engineering Society (Risley Branch): "Electrical Machines for Atomic Energy Purposes", L. Hack.

December 19.—Society of Instrument Technology (Newcastle section), at Kings College, Newcastle: "Instrumentation of Nuclear Reactors", T. R. Thompson (Ericsson Telephones Ltd.).

World News



A recent picture of the Dounreay sphere. (Courtesy *The Scotsman*.)

INTERNATIONAL

O.E.E.C. Working Groups, set up for the establishment of joint undertakings in the field of nuclear energy, have commenced their activities. The first group is studying means of speeding up the construction of power stations, and the second the establishment of a joint research centre. Both groups have appointed a small number of experts to draw up technical proposals for their next session and are to report to the Steering Committee for Nuclear Energy of the O.E.E.C. early next year.

UNITED KINGDOM

Inkley Point in Somerset, on the Bristol Channel coast, has been selected by the C.E.A. for its third nuclear station, subject to the approval of the usual authorities.

A nuclear reactor for Wales has been suggested by the Welsh Economic Development Council in a fourfold approach to the A.E.A., the C.E.A., the Ministry of Fuel and Power and the Minister for Welsh Affairs.

Three university scholarships for honours degrees in electrical and mechanical engineering, tenable at Southampton University, and four exhibitions for diploma courses in technology are to be awarded annually by Hoover Ltd.

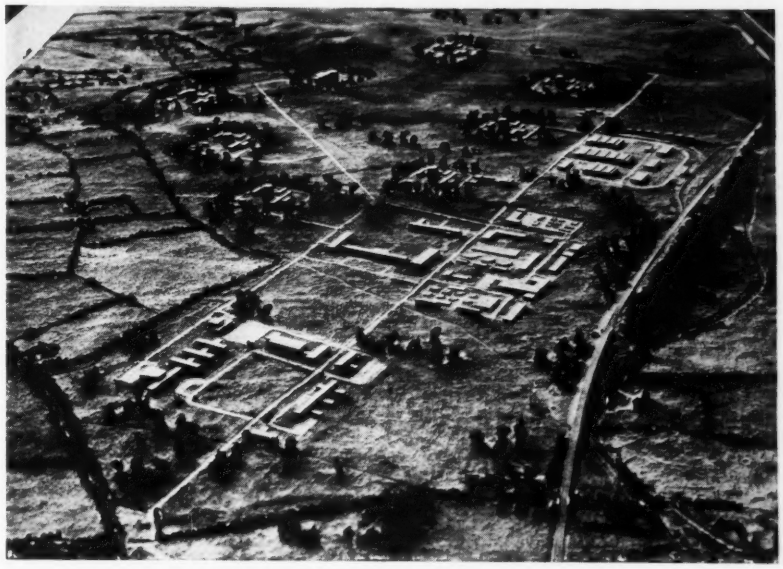
A new consortium in the atomic field was forecast in early November. The companies concerned are International Combustion Ltd., Richardsons, Westgarth and Co. Ltd., Trollope and Colls Ltd. and Crompton Parkinson Ltd.

Babcock and Wilcox are building the reactor vessel for the N.P.D. reactor that Atomic Energy of Canada Ltd. are constructing at Des Joachims.

An atomic energy exhibition is being held in the McLellan Galleries, Glasgow, in early January. It is being sponsored by the South of Scotland Electricity Board.

Calder Hall has resumed operation after a shut-down for a thorough inspection and exchange of fuel elements. The first reactor was handed over on May 18, diverged on May 22 and by August 8 was running at 100 MW (heat). The flux distribution whilst not optimum was stabilized at this juncture. During shut-down steel absorbers have been inserted to promote flattening of the reactor and to allow the control rods to be more fully withdrawn.

Measures taken by the Factory Inspectorate to deal with radiation hazards in industry include the employment of a full-time physicist in an advisory capacity and the supply of information to factory inspectors, notification of the Inspectorate by the A.E.A. of companies supplied with isotopes and special training of the inspectors, including courses at Harwell.



Model of the proposed A.E.A. research establishment at Winfrith Heath, Dorset. As shown above, the establishment will extend from Giddy Green (foreground) to Blacknoll, some two miles, covering 688 acres. The buildings within the circle of trees are the eight experimental reactors. Buildings on the right are: foreground, administration buildings; centre, effluent disposal; background, stores.

AUSTRALIA

Helicopter prospecting for minerals has commenced in the western part of Tasmania. The aerial survey is expected to last five months, according to a message from Hobart.

The Duke of Edinburgh visited the Rum Jungle open-cut uranium mine in mid-November. After inspecting the cut, which is a quarter of a mile across and 150 ft. deep, according to a *Times* report the Duke inspected the ore-treatment plant.

The Australian A.E.C. has established an isotope section with an information and advisory service to assist users and potential users of isotopes in industry.

CANADA

Hamilton College, of McMaster University, Hamilton, Ontario, is to have a nuclear research reactor.

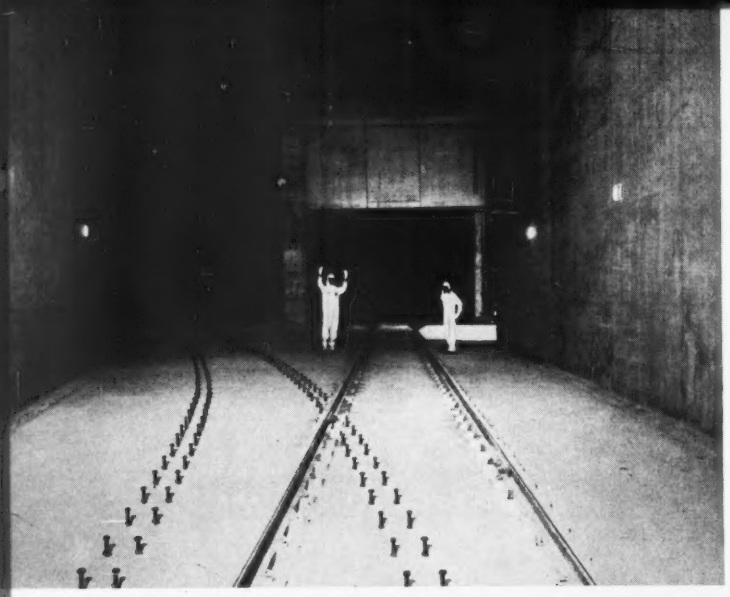
FRANCE

Further details are now available about the Marcoule reactors. G1, described in *Nuclear Engineering* for April, 1956, was made critical in January and, as recorded in our November issue, was actually generating electricity by September 28, the ultimate output being 5 MW. G2, with a heat output of 70 MW (30 MW electrical), is planned to be in operation by the end of 1957 and G3, with a similar output, by the middle of 1958.

GERMANY

Frankfurt University is to have a 50-kW nuclear reactor, a Reuter report announces. It is to be built by Atomics International Inc.

The September/October issue of Die Atomwirtschaft contains a world survey of research and power reactors planned.



Entrance to a 500 - ft. burial tunnel at the A.E.C.'s Harford plant, for permanent burial of waste material with long - life emission. The gate is water - filled to provide a radiation barrier. On the left is provision for a second tunnel when the first is filled.

The Japanese delegation at the Nuclear Energy Division of Elliott Bros. Ltd. Left to right: Dr. S. Hoki, Prof. S. Tiujimoto, Mr. J. Hirota and Mr. M. V. Needham, head of the Elliott Nuclear Division.

ITALY

Tenders for a single-reactor nuclear power plant of 100-150 MW will be requested from all the consortia at the beginning of December by La Centrale of Milan, who control a large proportion of Italy's electricity generation. A delegation from that company is visiting the United Kingdom as we go to press.

JAPAN

Electronics industry. It is reported that the Ministry of International Trade and Industry is planning to establish a programme for the promotion of the electronics industry, to begin in fiscal year 1957/8. The steps to be taken include the forming of an electronics department in the Ministry's Heavy Industries Bureau, and the establishment of a research institute at a cost of some 3,000 million yen.

A licence has been issued by the A.E.C. to Marubeni-Iida for the export of a 50-kW homogeneous research reactor for use by the Japan Atomic Energy Research Institute.

A delegation from Japan was in Britain in mid-November, and it appears highly probable that a power reactor of the Calder Hall type will be purchased. Visits were paid to a number of manufacturers, including Elliott Bros., Mitchell Engineering Ltd. and representative companies of the four consortia.

NEW ZEALAND

A National Institute of Nuclear Science has been recommended in a report by the professional board of Victoria University College, Wellington.

PORTUGAL

A particle accelerator of the Van de Graaff type has been purchased by Portugal's Junta de Energia Nuclear for use in research and training of nuclear physicists. The generator, a 2-MeV unit, is being built by the High Voltage Engineering Corporation, of Cambridge, Mass.

U.S.A.

A man-power survey in private atomic energy industries is being undertaken by Atomic Industrial Forum Inc. under contract to the A.E.C. This will be the first step in a four-part survey which will also cover industry carrying out work for the A.E.C.; universities and research institution; and Government requirements for direct employment of nuclear scientists and engineers.

Terms for loans to privately-owned utilities for financial assistance for the construction of atomic power plants in the same way as for conventional power plants have been agreed between the Export-Import Bank of Washington and the A.E.C. Amongst other requirements, nations must have completed an agreement for co-operation with the United States.

The Mellon Institute has announced plans for a new laboratory for its newly-established Department of Radiation Research, to be located 20 miles east of Pittsburgh. Construction is expected to be complete by the late summer of 1957. One of the first items of equipment will be a 3-MeV Van de Graaff generator, already on order from High Voltage Engineering Corporation Ltd.

Public hearings began in mid-November on the Power Reactor Development Company's 100-MW fast breeder reactor, construction of which is under way at Monroe, Michigan, to which objections have been raised by three labour unions.

Fellowships in nuclear engineering are being established by the A.E.C. About 150 fellowships worth $1,800, plus tuition and dependency allowances, will be awarded. Details of the complete programme will be announced later.

A proposal by the Babcock and Wilcox Co. of New York for the construction of a 20,000-s.h.p. unit for a merchant ship has been accepted by the A.E.C. as a basis for contract negotiations. The reactor is of the pressurized-water type and is to be completed in 39 months.

A London office of A.E.C. is to be opened and Dr. E. L. Brady is expected to open it at the beginning of December. A Paris office has also been opened.

The 1957 Nuclear Energy Conference is to be held from March 11-15, 1957, in Philadelphia, the sponsors being the Engineers Joint Council. An international Atomic Exposition is also to be held.

A contract has been placed with the General Dynamics Corporation by the A.E.C. for a feasibility study on a gas-cooled reactor for an oil tanker, utilizing a closed-cycle gas turbine.

A new joint company for expansion of research, development and production in the atomic energy field is announced by Sylvania Electric Products Inc. and Corning Glassworks.

The Army Ionizing Radiation Centre announced in the November issue of *Nuclear Engineering* will now, it is stated, be located in Sharpe General Depot at Stockton, California.

Four southern power companies have pooled their resources to form a non-profit corporation known as Carolina-Virginia Power Associates Inc. which will build, it is stated, a large atomic power plant. The companies involved are the Virginia Electric and Power Co., the Carolina Power and Light Co., the Duke Power Co. and the Southern Carolina Electric and Gas Co.

U.S.S.R.

Ten members of a Soviet delegation recently visited Britain to study methods of technical education. In addition to the Institutions and the Cavendish Laboratory, several industrial establishments were visited, including the B.T.H. and English Electric works at Rugby.

Orbits in Industry

Asking Lord Citrine to open the new high-voltage laboratories at the Ravenhead works of Pilkington Bros. was a nice gesture, since as plain Walter Citrine he worked there as an electrician in 1910 and it must have caused him a few sentimental heart-searchings when he was shown some of his time-sheets for that year. Although the particular ones unearthed recorded that he worked a great deal of one Sunday, and foremen in 1910 were vastly different from those of today, that crowded Sunday of hard and dirty toil must look nowadays like a rest cure, and a 54-hour week an impossible ideal.

The new laboratory, incidentally, is a very fine piece of work. Many of the older establishments, built in the days when 132 kV was regarded as an enormous step forward in working voltage, must be feeling a bit pinched for space nowadays, whereas the Pilkington establishment seems roomy enough to test anything ever likely to be built. There must be a limit to transmission voltages soon. The twin-conductor system used by the 275-kV grid cuts down corona very considerably, and there were some remarkable results obtained some ten years ago with four conductors, but the limit must come when it is easier for the charge to leak off into the atmosphere as a brush discharge than to stay on the conductor and do useful work.

Thorium and Cerium

Another research laboratory opened within a week of the above was, by a peculiar coincidence, distantly connected with it. Thorium Ltd. opened new research laboratories in Ilford and, amongst many other products of this company are colouring materials used in glass manufacture. It is hoped to be able to say more about these laboratories and the company's products at an early date.

Brussels '58

There still seems to be a certain vagueness about the "Brussels Universal and International Exhibition 1958", to give its full title. It is not a trade fair as some seem to think, nor is it a Belgian exhibition. It is a truly world-wide affair and the question of whether Belgium is or is not a potential market for one's goods simply does not arise. National prestige demands that our exhibit is truly representative of the best of British industry. There is no question of "taking stand space"—in fact it is doubtful whether any single commercial concern could afford to do so. But associations and commercial concerns, large and small, can still help to put British industry on top by assisting B.E.A.M.A. in their efforts to stage a fitting exhibit.

Journey to Carthage

Since some of the technical Press have said harsh words about facilities at Press visits to A.E.A. establishments, and this column has been amongst them, let us, in common fairness, pay tribute to a first-class job the day before DIDO was officially opened. Short of laying on Scientific Officers (J.G.) to carry the Press "piggy-back" round the establishment, it is difficult to see what more could have been done. Quite apart from the excellent arrangements for transport and hospitality, there seemed to be a total lack of what one might term the Official Manner. Nowhere seemed to be barred; one was free to wander into DIDO's innermost sanctuary and snoop around at will. PLUTO, half constructed, did not even have a welder working up in the roof and dropping showers of hot slag—a favourite gambit in many power stations for keeping visitors out of the way. It was, in fact, a first-class piece of work on everybody's part and should do a great deal towards cementing friendly relations between Harwell and the Press. If there is another visit, one small suggestion might not come amiss: about double the number of guides. When one is in a confined space only the first two or three in can really hear what the guide is saying, and unless one is a Keen Type (i.e., one whose colleagues are all called Jack) it is not possible to be first all the time.

"Great Day"

The A.E.A. has recently released another film of Calder Hall which combines a very pleasing colour record of the opening ceremony by H.M. the Queen, with a film about the station itself containing a simple explanation of the operation of the station, interspersed with animated diagrams. The whole is pitched —and very cleverly pitched too—at the level of the general public. It has already been booked by a number of cinemas and should be extremely popular. It was made by the same people (Ace Distributors Ltd.) who made the original film, which should be sufficient guarantee of its quality. It is, incidentally, being translated into eight languages for overseas distribution.

Coals to Newcastle?

It was once said that if the domestic refrigerator had developed in Britain untouched by American influence, it would have had an outer finish of either Jacobean oak or black-leaded cast-iron, and varnished wood interior fitments. This, perhaps, is a little unkind. It is, however, only too true that we often lead the world on fundamental problems and the U.S. beats us in the commercial application of those problems Mr. Neil Catton, of Du Pont de Nemours, lecturing a few weeks ago on recent developments in synthetic rubbers, such as Neoprene and Hypalon, put it (quoting from memory): "The British are first rate at getting an idea, but in the States we seem to be able to pick it up and run faster with it". Which is only too true. Apart from well-known examples like radar, one might remember that the first turbine in the U.S. ever to run at 1,000°F was built by the B.T.H. in Rugby—but there is not space to quote half the examples that come to mind. It is therefore refreshing when British plant is chosen in an industry where the Americans have led for years. On air conditioning, one would think that it was not possible for us to compete with the U.S., yet at the new Technical Centre that the General Motors Corporation have opened at Detroit there is an air-conditioning system supplied by Thermotank Ltd., of Glasgow. The installation in the Isotope Laboratory was particularly interesting, since, unlike most systems, it uses no recirculated air—for obvious reasons.

Physician Heal Thyself!

This column will always support the statement made during the opening session of the B.N.E.C. that there was a disinclination to publicize our achievements on Calder Hall. What is, however, more than a little amusing is that the plaint regarding "typical British reticence" should come from an industrialist, whose own company (and its subcontractors to the third and four generation) were exceedingly reluctant to part with any real information and showed a distaste for publicity that was positively Garboesque.

Talking about Calder

In our two lists of contractors engaged in Calder, it was not made clear under "Burst-slug Detection Gear" that the rate-meters were supplied by General Radiological Co. Ltd. Also, New Western Ltd., of Meadow Lane, Leeds, 11, was credited with the supply of meters. This was incorrect, as they supplied not meters but the panels and desk for the reactor control room and erected the instruments, piping and wiring as well as carrying out the testing.

Success Story

Jubilees and centenaries are usually the occasion for emphasizing how businesses grew from small beginnings. It is not often, however, that one hears of rapid expansion in such a short time as ten years—particularly the ten post-war years that have now elapsed—and it is interesting to hear from Fielden Electronics Ltd. the way in which they have expanded from one man and an idea to a payroll of more than 300 in three stages. There is also an associated company in the U.S. as well as in Australia, and a subsidiary research company in North Wales. This certainly refutes in no uncertain fashion the widely-held theory that this sort of thing is impossible in these days of regimentation and restriction. The romance of individual enterprise, it seems, is not yet dead.

Industrial Notes

Flexibox Ltd., of Nash Road, Trafford Park, Manchester 17, announce that they have acquired the Government factory in Ballymena, 27 miles from Belfast and 20 miles from Larne, for the production of their Flexibox and Sealol mechanical seals and for the manufacture of lapping machines and hard facing processes. The Flexibox seal, first developed at the Manchester Oil Refinery, has of course, many applications in nuclear engineering work.

The Management Consultants Association has been formed to pool research on newer problems of management and to exchange experience with older problems. The member firms, Associated Industrial Consultants Ltd., Personnel Administration Ltd., Production-Engineering Ltd. and Urwick Orr and Partners Ltd., will retain their separate identities and will continue on a competitive basis. The secretary of the M.C.A. is Mr. F. S. Tuffin and its address is 4 London Wall Building, London, E.C.2 (telephone LONdon Wall 4080).

Hepburn Conveyor Co. Ltd., of Rosa Works, Wakefield, Yorkshire, announce that they have obtained the sole British manufacturing rights of shot-blasting and dust-control equipment of the Pangbourn Corp., of Hagerstown, Maryland, U.S.A.

Racal Engineering Ltd., of Western Road, Bracknell, Berks, announce that they have appointed Farnell Instruments Ltd., of Hereford House, North Court, Vicar Lane, Leeds, 2 (telephone Leeds 32958), sole distributors in the North of England area for their range of digital counters and frequency meters. Farnell will undertake special applications and servicing problems.

Humphreys & Glasgow (Canada) Ltd. has been incorporated as an associate company of Humphreys & Glasgow Ltd., of Humglas House, Carlisle Place, London, S.W.1. The address of the new company is 837 Eglinton Avenue West, Toronto, 10, Ontario, and its activities entail engineering and plant construction for the gas, petroleum, chemical and other process industries.

The National Council for Technological Awards now has its own premises at 9 Cavendish Square, London, W.1 (telephone MUSeum 1978).

The Plessey Group of Companies announce the establishment of an office in Amsterdam to provide local contact and expand existing markets in Northern Europe. Located at Singel 160, Amsterdam C, the office will form an integral part of Plessey International Limited, the Group's overseas marketing organization, and will supervise Plessey interests in Northern and Central Europe.

Catalogues and Publications

Metallic Flexible Controls.—The Compoflex Co. Ltd., of 23 Northumberland Avenue, London, W.C.2, issued a 30-page catalogue of light and heavy flexible-sheath cable transmissions of the push-pull and spring-return types for remote-control purposes. Both light-duty and heavy-duty drives are listed, loads ranging from 35-1,500 lb. The information is extremely comprehensive, with drawings and full dimensions of every rating and type.

Newalls Insulation.—A compendium of catalogue sections on heat insulation; insulating bricks; Paxmarine; sprayed Limpet asbestos; sound insulation and cold insulation; totalling some 260 pages, in a stiff leather cover, from Newalls Insulation Co. Ltd., Washington, Co. Durham. Production is of a high standard. Copies are being distributed to technical libraries, public libraries and associations throughout the country.

U.S. Isotope Price List.—From Union Carbide and Carbon Corporation, 30 East 42nd Street, New York, 17, comes a revised price list of stable isotopes available from Oak Ridge National Laboratory.

U.S. Analogue Computers. — Shortened catalogue (No. C703) from the Berkeley division of Beckman Instruments Inc., 2200 Wright Avenue, Richmond, 3, California. Covers systems for data reduction, handling and logging, industrial measuring and recording, and industrial process control. Three new analogue computers and four components for control systems are outlined, and components include amplifiers, electronic multipliers and function generators.

The catalogue also describes newly-developed frequency meters, decimal-counting units, events-per-unit-time meters, time-interval meters, nuclear scalers and nuclear sample changers.

Alcotwin Heat Exchangers. — Bulletin FH3 from Alco Products Inc., 30 Church Street, New York, 8, gives further particulars of the longitudinal-fin twin-tube heat exchangers described in *Nuclear Engineering* for August. Includes dimensions and pressure-drop charts.

Tretol Specification Sheets.—First three of a new series of specification sheets on specialized building products and protective paints which are being issued by Tretol Ltd., Tretol House, The Hyde, London, N.W.9.

Plessey at Towcester. — A 48-page brochure describing the activities of the Chemical and Metallurgical division of the Plessey Co. Ltd., Ilford, Essex. Products covered include Caslite iron dust cores; Caslam flake iron cores; Cascap ceramic capacitors; Caslox hard magnetic ceramics; Caslode microwave absorbers; Ferramic soft magnetic ceramics; and Castanet tantalum electrolytic capacitors.

Feed-water Treatment.—Hydrazine for boiler feed-water treatment is the subject of a brochure produced by Whiffen and Sons Ltd., North West House, Marylebone Road, London, N.W.1. In addition to a general discussion of the advantages of this treatment, which acts as an oxygen scavenger without the addition of dissolved solids, the publication deals with the practical aspects of water treatment, including the protection of standby plant.

Alco Products Review. — The Winter 1956 issue of this publication, issued by Alco Products Inc., of 30 Church Street, New York, 8, contains articles on the design features of the APPR reactor and on Alcoplate (electroless nickel plating) for corrosion prevention.

Isotope Index. — Scientific Equipment Corporation, of 23 Hawthorne Lane, Indianapolis, 19, Indiana, have issued a complete (U.S.) guide to the isotopes and their labelled compounds. Running to 64 pages, this gives full particulars, including the supplier, catalogue numbers, specific activities and typical prices of various quantities. More than 24 pages are devoted to carbon-14 labelled compounds alone and 45 suppliers are listed. The book sells at $2 in the U.S. and $2.50 abroad.

Precious Metals in Industry. — A brochure from Johnson Matthey and Co. Ltd., of 78 Hatton Garden, London, E.C.1, gives a general idea of some of the products and services available from the divisions of the company. The production of the brochure is of an exceptionally high standard and the illustrations, of subjects as diverse as Mallory spot-welding electrodes and a 2½-ton silver ingot, are of exhibition quality.

Magnetic Crack Detection.—"Seeing Isn't Always Believing" is the title of a brochure issued by Solus-Schall Ltd., of 15 Clipstone Street, London, W.1, describing non-destructive testing by Magnaflux methods, of which they are the British licensees for the U.K., Europe and the Commonwealth (excluding Canada). Products manufactured include Magnaglo fluorescent magnetic inks and Zyglo fluorescent penetrant for non-magnetic materials; Statiflux powder for electrostatic crack indication on non-conductors such as ceramics; Partek filtered particle inspection for unfired ceramics; and Stresscoat brittle lacquer for stress analysis.

Airborne Geophysics.—Brochure from Hunting Geophysics Ltd., 4 Albemarle Street, London, W.1, describing combined airborne geophysical methods of mineral prospecting.

Cutting Oils.—A series of 11 technical bulletins on soluble cutting oils for economic machining of ferrous and non-ferrous metals, also lubricating oils and rust and corrosion preventatives from the Mobil Oil Co. Ltd., Caxton House, London, S.W.1.

Personal

Mr. G. T. Baker.

Mr. R. W. Boughton.

Mr. E. J. Mansfield has been appointed works director and **Mr. E. J. Warren** sales director of Edwards High Vacuum Ltd.

Mr. A. G. Stewart, chairman and general managing director of Stewarts and Lloyds, has been appointed part-time member of the Iron and Steel Board in succession to **Sir Andrew McCance**.

Mr. H. J. F. Gourley, senior partner in the firm of chartered civil engineers, Binnie, Deacon and Gourley, has been elected president of the Institution of Civil Engineers.

Mr. Alexander Longair, a physicist, has been named director for atomic research with Canada's Defence Research Board. Mr. Longair joined the Canadian Defence Research Board four years ago as staff officer for special weapons.

Mr. G. W. Hall, A.F.R.Ae.S., has been appointed a vice-chairman of The Fairey Aviation Co. Ltd. In addition to his appointment as managing director. **Mr. Richard Fairey** has been appointed a vice-chairman also and has relinquished his position as general manager. **Mr. R. L. Lickley**, B.Sc., D.I.C., M.I.Mech.E., F.R.Ae.S., has been appointed technical director (retaining his position as chief engineer), **Mr. J. C. Macpherson**, A.C.A., financial director (remaining as secretary), and **Mr. Alan Vines**, A.F.R.Ae.S., A.M.I.P.E., production director.

Mr. W. L. Beckett, formerly London area sales manager of The National Gas and Oil Engine Co. Ltd., has been appointed London manager of the company and a director of its subsidiary, National Oil Engines (Export) Ltd. In both positions he succeeds **Mr. F. D. Langley**, who has retired.

Mr. G. Sims-Davies has been appointed equipment manager of British Oxygen Gases Ltd., with **Mr. Robert Fannon** as his assistant. Mr. Sims-Davies was previously the district engineer for the firm's Lancashire division and Mr. Fannon superintendent of the process development section at British Oxygen's sales technical service department at Cricklewood.

Mr. A. M. Harris, Dr. W. D. Bennett, Dr. A. J. Goodjohn and **Dr. J. T. Rogers** have joined the General Atomic Division of Canadair Ltd., Montreal. Mr. Harris is in charge of the engineering of all nuclear projects; Dr. Bennett is acting chief of the development section comprising physicists, metallurgists and engineering specialists; Dr. Goodjohn will work on special calculations on all projects of the division; and Dr. Rogers is to be in charge of mechanical engineering and thermal problems on nuclear projects.

Mr. R. W. Boughton has been appointed sales manager of Fleming Radio (Developments) Ltd.

Mr. J. R. Arundale has retired from the office of secretary of Simon-Carves Ltd. owing to ill health. **Mr. R. S. Helliwell**, M.A., A.C.A., the company's accountant, has succeeded him.

Mr. M. G. B. Mason has been appointed sales representative for the Northern half of the country for Morganite Resistors Ltd. and **Mr. R. F. G. Whitehouse** for the London area and the South.

Dr. A. M. Uttley has been appointed superintendent of the control mechanisms and electronics division of the National Physical Laboratory, Teddington. He succeeds **Mr. R. H. Tizard**, who has taken up an appointment at the London School of Economics.

Mr. Potter Trainer has been named manager of New Optical Products Department at Baird Associates-Atomic-Instrument Co. Mr. Trainer, a member of the Instrument Society of America, has been working on the development of new products in the infra-red field for the past year. **Mr. Wilburt M. Draisin** has been appointed promotions manager and **Arthur L. Krasnow** assistant sales manager of the company.

Dr. R. M. Burns, a senior scientific adviser to Stanford Research Institute, has been awarded the 1956 Acheson Medal, it is announced by the American Electrochemical Society. This biennial award is made for outstanding contributions to "the advancement of any of the objects, purposes or activities fostered or promoted by the Society".

Dr. Roman Schmitt, Dr. R. L. Wolke, both nuclear chemists, **Dr. Egil K. Bjornerud**, a nuclear physicist, and **Dr. W. F. Brown**, a mathematician, have joined the staff of General Atomic Division's John Jay Hopkins Laboratory for Pure and Applied Science.

Mr. H. F. Bibby, B.Sc. Tech., A.M.I.E.E., A.M.I.Mech.E., has been appointed assistant general manager of Metropolitan-Vickers Electrical Export Co. Ltd. He is succeeded as manager, American division, by **Mr. C. H. de Nordwall**, M.I.E.E., who retains his seat on the board of Metrovick do Brasil (Eletricidade) Ltda.

Dr. R. Kappeli, chairman and managing director of CIBA, has been conferred with the honorary degree of Doctor of Technical Science of the Swiss Federal Polytechnic Institute.

Dr. A. M. Uttley has been appointed superintendent of the control mechanisms and electronics division of the National Physical Laboratory, Teddington. Dr. Uttley will take up his appointment early in the new year.

Mr. P. M. K. Embling, B.Sc. (Eng.), has been appointed divisional director of the chemical plant division of The Power-Gas Corporation Ltd. He was formerly manager of the division. **Mr. D. R. Brown**, who was manager of the blast-furnace division of Ashmore, Benson, Pease and Co., has been appointed divisional director responsible for the promotion and development of blast furnace and ancillary plant marketed by the company.

Mr. H. Brynielson, of Sweden, is to be the first director-general of the International Atomic Energy Agency on formal approval of the I.A.E.A. by the governments concerned.

OBITUARY

It is with regret that we have to announce the death of **Mr. G. T. Baker**, M.Sc., who was recently appointed a director and research manager, switching, of British Telecommunications Research Ltd. Mr. Baker was 48.

FORTHCOMING EXHIBITIONS

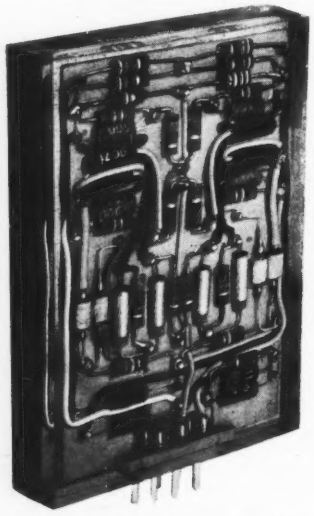
1957

PHILADELPHIA:	**International Atomic Exposition and Nuclear Congress. March 11-15.**
COPENHAGEN:	**11th International Fair (Technical Section). March 19-27.**
LONDON:	**Physical Society Exhibition of Scientific Instruments and Apparatus. March 25-28. Old and New Horticultural Halls.**
LOS ANGELES:	**Western Metal Congress and Exhibition. March 25-29.**
LONDON:	**14th British Radio Component Show. April 9-11. Grosvenor House, Park Lane.**
LONDON:	**6th Electrical Engineers' Exhibition. April 9-13. Earls Court.**
LYONS:	**39th International Trade Fair. April 27-May 6.**
BRUSSELS:	**31st International Trade Fair. April 27-May 12.**
LONDON:	**5th Factory Equipment Exhibition. April 29-May 4. Earls Court.**
BIRMINGHAM:	**British Industries Fair. May 6-17.**
LONDON:	**Instruments, Electronics and Automation Exhibition. May 7-17. Olympia.**
PARIS:	**47th International Trade Fair. May 25-June 10.**
LONDON:	**4th British Plastics Exhibition and Convention. July 10-20. Olympia.**
LONDON:	**21st Engineering Marine and Welding and Nuclear Energy Exhibition. August 29-September 12. Olympia.**
CHICAGO:	**2nd World Metallurgical Congress and 39th National Metal Congress and Exposition. November 2-8.**
LONDON:	**27th Building Exhibition. November 13-27. Olympia.**
NEW YORK:	**26th Chemical Industries Exposition. December 2-6.**

Processes and Equipment

Transistor Decade Counter

Venner Electronics Ltd., of Kingston By-Pass, New Malden, Surrey, have developed a decade counter and scaler which is stable and, by the use of transistors and germanium diodes, exceedingly compact; 86 components are mounted on a double-sided tagboard which, when encapsulated, measures only 4½ in. × 3¼ in. × ¾ in. and is fitted with an eight-pin plug. It requires only one power supply of 10 V



The Venner decade counter encapsulated in clear resin to show construction.

and the total consumption is 100 mW as a scaler and 160 mW as a counter. It is possible to connect one unit direct to another without any additional components, so that a 10-kc/s oscillator output is reduced to one pulse per second by using four units. By connecting a meter across each stage, short-period timing can be arranged to 0.1 millisecond.

The circuit employs four Eccles-Jordan stages with feed-back and the device will operate up to 30 kc/s.

Conducting Glass

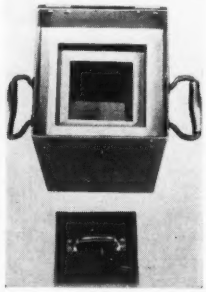
Glass with an electrically-conductive coating has been developed by James A. Jobling and Co. Ltd., of Wear Glass Works, Sunderland, well known for their Pyrex brand glassware. The E C glass, as it is known, is not yet generally available, but it is intended to produce it in panels of sizes 12 × 12 in. or 10 × 14 in. with a thickness of about $\frac{5}{16}$ in. It is also intended to produce tubes up to about 64 mm. diameter and up to 48 in. long. The resistance obtainable in the film ranges from about 10 to 200 ohms on a 12 × 12 in. plate, it being possible to produce resistances within ±5% of the specified value.

The power input allowable depends, of course, on the temperature and the effectiveness of heat transfer, but, as an example, a plate mounted vertically with both sides in free air at 70°F can be loaded to 10 W/sq. in. If the rate of heat removal is increased the loading can be increased, provided the maximum surface temperature does not exceed 350°C (about 662°F).

The film itself is transparent but presents a slightly blued appearance; the thickness is about 16 microinches, and is practically integral with the glass. Since the film acts as a reflector, the uncoated side radiates approximately twice as much heat as the coated side. If an additional metal reflector is located a short distance from the coated side, the radiation from the uncoated side may be as much as 80% of the total. At 327°C (622°F), over 75% of the energy is radiated at a wavelength of 4 microns and above. Silver contacts are normally used, but platinum can be supplied where corrosive conditions obtain. It is possible to clean or decontaminate these panels without any dismantling. The application of the tubes is likely to lie at the moment in fractional distillation columns, obviating the necessity for silvered and evacuated jackets.

U.S. Isotope Containers

Three new designs of shielded storage and shipping container are announced by The Atomic Centre Inc., of 489 Fifth Avenue, New York City. All three types have the same external dimensions of 8 in. × 8 in. × 10½ in. high, but differ in the



American isotope container with 2-in. lead lining.

thickness of lead lining which is, respectively, ½ in., 1 in. or 2 in., the latter giving adequate protection for 125 mc of Co 60 or 1,000 c of I 131. The steel outer container, arranged for padlocking, is of 11-g. steel plate, and is of seamless construction to withstand rough handling and, in the event of fire, to prevent the lead escaping. Hinged lifting handles are provided.

Floatless Level Indication

An ingenious floatless liquid-level switch is announced by Teddington Industrial Equipment Ltd., of Sunbury-on-Thames, Middlesex. Briefly, it consists of a differential thermostat, operating not on the difference of temperature but on the difference in rate of heat transfer, between two

Teddington floatless level switch.

elements and the liquid in question. Each of the two elements incorporates an invar rod and a moving sleeve, one having a heating element continuously energized (the power consumption being some 10 W), the other, for compensation purposes, being unheated. When the liquid immerses both elements, the rate of heat transfer is increased and the temperature difference is considerably reduced, causing the switch to operate. There is, of course, a time lag (about 35 sec. on the standard model) which serves to prevent hunting. Where this lag is considered too long for the particular application, there is a traction model available which has a consumption of 32 W and will operate inside 10 sec. One of the major advantages of this type of mechanism is, of course, that the switch mechanism can handle currents of reasonable size, without necessity for relays or amplifiers. The rating of the standard model is 5 amp. at 250 V a.c., while the traction model is rated for 24 V d.c. circuits at 1 amp. inductive or 2 amp. non-inductive. Mounting is by screwed boss (1¼-in. B.S.P. thread) or flange for four ¼-in. bolts.

Limit Switches

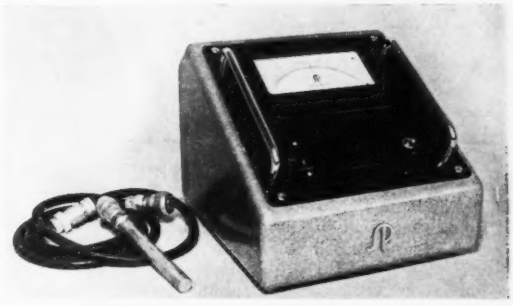
Smiths Industrial Instruments Ltd., of Chronos Works, North Circular Road, London, N.W.2, are marketing a new limit switch which is hermetically sealed against

Smiths limit switch.

water, dust and oil. It is supplied either as a single unit or in a bank of four. Two models are available, rated 2 amp. and 5 amp. at 250 V d.c. In each case the pre-travel can vary from 0.007 in. to 0.02 in., with a movement differential of 0.0004 in. to 0.002 in., and an overtravel of 0.25 in. The operating force is 5½ lb.

Remote Resistance Thermometers

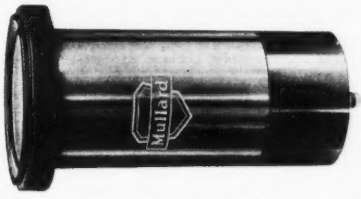
Savage and Parsons Ltd., of Watford, Herts, have developed a remote-reading resistance thermometer that is claimed to be the most accurate unit available on a commercial basis. With a sensitivity of ±0.1°C, the instrument is made in four models with ranges of −50-0°C; 0-50°C; 50-100°C and 100-150°C. The sensing element, which is of platinum, with a very small heat capacity to give rapid response to temperature changes, can be supplied in the conventional immersion type or as a flat unit suitable for affixing to surface or for interleaving. The unit, with a dry battery having a life of at least 400 hours, has a weight of 12 lb. packed for transit.



Savage and Parsons' new remote - reading resistance thermometer.

Mullard Geiger Tubes

In the May issue of *Nuclear Engineering* it is regretted that the two illustrations for the Mullard geiger tubes were both of different patterns of the liquid-sampling type. The mica end window cell, type



The Mullard geiger tube with thin mica window.

MX123, is as illustrated above; it is suitable for measuring very low-energy radiation, such as carbon-14, the end window being particularly thin—1.5 to 2.5 mg/cm^2.

New Welding Rectifier

A new constant-potential rectifier (C.P.R. 400) with a flat volt/ampere characteristic for Argonaut welding is announced by British Oxygen Ltd., of Bridgewater House, Cleveland Row, St. James's, London, S.W.1. This, it is stated, gives optimum self-adjustment of arc conditions and also reduces the possibility of burn-back. This means that control of the wire feed can be simplified, by dispensing with all voltage-sensitive relays; the wire feed starting by a simple current relay when the arc is established. A further simplification is that a magnetic amplifier is no longer required for the control of current and its omission reduces the cost and bulk of the unit.

British Oxygen's new C.P. welding rectifier.

This constant-potential rectifier is stated to be an important advance in the welding field, giving good self-adjustment of the arc; improved weld quality; a simplified and virtually foolproof control circuit; reduction in size and cost of the unit; easier set-up, and reduction in burn-back.

New Ultrasonic Transducers

Technical Ceramics Ltd., of Towcester, Northants, announce a new line of transducers for general ultrasonic work. Of the piezo-electric type, they are fabricated in a ceramic consisting of barium titanate in polycrystalline form, said to be strong, rugged, and able to handle high powers. Their overall characteristics, such as coupling coefficient, dielectric constant, temperature stability and sensitivity, are said to be superior to those found in other transducer materials.

The T.C.L. material can be fabricated to any desired shape or size, such as dual elements or mosaic arrays, in addition to simple rings, plates, discs or cylinders. They can be supplied with leads, or with tinned areas for soldering leads, and with various types of protective coating, such as simple waterproofing or hard plastic coatings or glaze, to resist cavitation and corrosion.

Filter Material

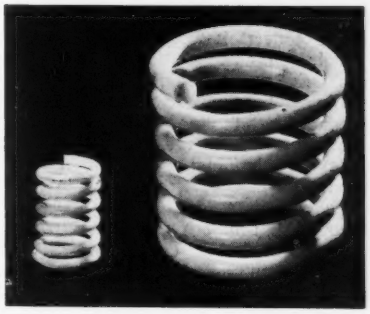
From Air Control Installations Ltd., of Ruislip, Middlesex, we have received a sample of Amer-glas material for filter units, in which the density of the material increases from front to back, thus allowing the larger particles to be trapped at the front of the filter and reducing the clogging at the discharge side. It is stated that 1 sq. ft. of this material 2 in. thick contains some 37,000 ft. of glass-fibre, which is coated with a thermoplastic known as Viscosine to form an adhesive film to hold collected dust. While non-inflammable, it is said to be "burnable" so that fouled material can easily be disposed of. The material is manufactured by the American Air Filter Co. Inc., for whom Air Control Installations Ltd. hold exclusive selling rights in Britain.

New Barrier Cream

Syl, a new barrier cream material containing silicone compounds, has been developed by Lloyd-Hamol Ltd., of Batley, Yorkshire. The silicone content gives a water-repellent action, thus resisting penetration by aqueous solutions, but permeable to vapour and gas, allowing the skin to "breathe" in its usual manner. Actual tests and demonstrations have shown some remarkable results, it being possible to remove the cream and its associated dirt (even with mixtures of soot and oil) with ease, although the film is normally resistant to liquid and liquid irritants, including acids.

P.T.F.E. Coating for Springs

Polytetrafluorethylene (P.T.F.E. or Fluon), well known for its resistance to chemical attack and high temperatures, and for its comparative difficulty of



Springs coated with P.T.F.E. by Crane Packing Ltd.

moulding, is now being applied as a coating to springs by Crane Packing Ltd., of Slough. This development now enables springs to be treated so that they are completely unaffected by normal corrosive agents or moisture, and will be self-lubricating and non-sticking.

New Sizing Compound for Glass-fibre

A new organo-silicon size for glass cloth in laminate manufacture is announced by Midland Silicones Ltd., of 19 Upper Brook Street, London, W.1. Known as Experimental Silicone D9132, it has been developed by the Dow Corning Corporation in the U.S.A., and is said to represent a notable advance over previous methods of sizing in the production of phenolic, epoxy, polyester, and silicone laminates, in that it can be applied from an aqueous solution, needing only a simple drying operation.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. each (including postage).

B.P. 755,558. Polymeric zirconium compounds and method of preparing same. J. H. Balthis. To E. I. Du Pont de Nemours and Co.

Polymeric zirconium esters and polymeric zirconium carboxylates are prepared by heating an alkyl ortho-zirconate (tetraethyl zirconate) and from 0.5 to 4 mols of a straight chain, saturated, aliphatic monocarboxylic acid (stearic acid) per mol of ortho-zirconate until a stable, soluble, polymeric zirconic acid ester is formed. The product is a colourless to light brown liquid or solid and readily soluble in organic solvents. Lead scavengers in petrol, rust inhibitors, catalysts in coating compositions are dispersing agents and water-repellents.

B.P. 755,601. Separating hafnium from zirconium. B. A. J. Lister, J. F. Duncan, J. M. Hutcheon. To: U.K. Atomic Energy Authority.

Substantially complete separation of zirconium from hafnium by elution of cation exchange material. Preferred exchange materials are sulphonated polystyrene resins (Dowex 50; Zeokarb 225) arranged, for example, in the form of a 4-ft. column in an inert tube of 1 in. diameter. The resin may be supported on a perforated plate and washed with nitric acid to convert it to acid form. As an example, an acid solution of zirconium oxychloride or other soluble zirconium salt containing hafnium impurity (2%) was introduced into the top of the column with a tracer quantity of radioactive zirconium (Zr 95) and hafnium (Hf 181). 10 g of zirconium could be treated by the resin in the column at one time. Afterwards aqueous N sulphuric acid was passed through the column. The eluate was continuously monitored by a Geiger-Müller tube and amplifier. The eluate contained from 98 to 99% of the zirconium originally present, and oxide precipitated from the solution showed on spectographic analysis less than 0.01% hafnium.

B.P. 755,903. Utilization of the nuclear combustion of hydrogen. G. F. Hemens.

This patent relates to the nuclear reaction of hydrogen with nitrogen. Hydrogen nuclei, if placed in the active zone of an explosion or in a region of high temperature, behave as bombarding particles. The patent contemplates the subjection of some ordinary chemical substance containing hydrogen (water) to high temperature or to the shock of an explosion in order to release on a finite scale the intrinsic energy of matter by fusion. A deuterium compound (LiD or ND_3) will function as a detonator, the heat released in the nuclear combination of Li or N and D or of D and D or of Li and Li, etc., serving to ignite the main body of combustible material, for example, LiH, NH_3 of an air-water mixture, the water being ordinary water. A number of possible arrangements are shown, such as adaptations of ordinary jet engines with initial ignition effected by a H-N flame.

B.P. 756,049. Liquid-liquid extraction columns. J. D. Thornton. To: U.K. Atomic Energy Authority.

Refers to "pulsed columns" in which a pulsating pneumatic pressure is applied to the surface of the liquid in a tube communicating with the lower part of the column. The pulsating pressure may be produced by a piston (preferred), or by a bellows or by injection and escape of pulses of compressed gas (air). Process liquors in the column do not come in contact with moving parts, so that no wear or corrosion can occur and maintenance is simplified.

B.P. 756,729. Radiation analysers. V. Z. Williams. To: Perkin-Elmer Corporation (U.S.A.).

Refers to the analysis of mixtures in order to determine the amount of a component (gas of interest) whose absorption bands are overlapped by the bands of other components. The instrument is of the two-radiation beam type and includes a recording device. Infra-red radiation is preferred.

B.P. 757,015. Process of nuclear fission. To: Stichting voor Fundamenteel Onderzoek der Materie (Netherlands).

When nuclear fuel is used in the form of a suspension possessing a high viscosity, then difficulties may arise in cases where the fuel suspension flows through the reactor under gravity or if the suspension cannot easily be pumped. Furthermore, the fission products are hard to separate from the carrier liquid. These drawbacks are eliminated by diluting the suspension, outside the reactor, with an additional amount of carrier liquid. This additional amount is again separated from the carrier liquid before the suspension returns into the reactor. Thus the suspension is circulated outside the reactor in the diluted state. The separated carrier fluid may be partly freed of fission products dissolved therein and is then subsequently re-used for diluting the fuel so that a continuous purification of the fuel is achieved.

B.P. 757,413. Titanium alloys and their application. J. M. Butler. To: British Non-Ferrous Metals Research Association.

Titanium base alloys consisting of from 3% to 10% aluminium, from 1% to 20% zirconium, the balance being titanium (iron, nitrogen, oxygen, carbon not exceeding 0.25% each), exhibit a markedly better combination of hot-working properties and creep-resistance than titanium base alloys of usual composition. These alloys have possibilities for components operating at up to 400°C.

B.P. 757,910. Production of pure titanium or zirconium. J. P. Levy. To: J. P. Levy, D. H. Pickard and L. Pickard. (Additional to 722,184.)

The main specification (722,184) describes the reaction of the tetrachloride of the required metal in the vapour phase in the presence of an inert gas stream (argon, helium, neon) with magnesium metal vapour. The reaction products are then passed through a cooling zone. The inert gas stream was to draw the vapour from a pool of boiling metal in a vessel surrounding the reaction vessel through a venturi throat. Contrary to original considerations, according to which excess tetrachloride was preferred, it has now been found that excess magnesium is preferable. It has further been found that the inert gas stream should be divided into two interconnected circuits; one (major) for conducting the reaction products to the collector, whilst the other (minor) one returns to the low-pressure side of the main circuit.

B.P. 758,930. Magnetic system for use with electron beams. To: Philips Electrical Industries Ltd. (Netherlands).

Refers to the control of a beam of electrically - charged particles by two separate pole shoes arranged on opposite sides of the beam. The shoes are secured to a permanent magnet and consist of two narrow strips of soft iron formed with two bends. It has been found that "astigmatism", i.e., the deformation of an initially circular beam into an elliptical one, can be avoided by decreasing the reluctance of the pole shoes towards their free ends by increasing their width towards their free end (if of uniform thickness), or by increasing their thickness (if of uniform width), or by increasing their permeability (e.g., with ferrites).

B.P. 759,160. Production of carbon masses. I. B. Mason. To: U.K. Atomic Energy Authority.

Refers to high-density graphite masses. The mass is moulded or extruded from finely powdered carbon mixed with a cokable binder. The plastic mixture is then tightly packed in a refractory powder (carbon grist) in a pressure-tight container and baked. A density of 1.635 was obtained, which, after graphitizing, had increased to 1.73.

B.P. 759,413. Titanium-clad steel and methods of manufacture thereof. To: Lukens Steel Co. (U.S.A.).

One side of a titanium sheet is electroplated with iron or nickel. A steel backing plate is then placed against the electro-plated face of the titanium sheet and a parting material (aqueous graphite suspension) introduced at the unplated side; a steel cover plate is applied and the periphery of the pack hermetically sealed. An inert gas (argon) is then caused to flow between the steel plates while the pack is heated to promote bonding of the titanium sheet to the backing plate, bonding being effected by reducing the pack, e.g., by rolling. (See also: 759,468 and 759,469 div. out of 759,413.)